relationship just outlined points to a translation of the isohaline for 32 per mille about 100 miles westward from the location occupied by it before the current begins to flood past Cape Sable in appreciable volume.

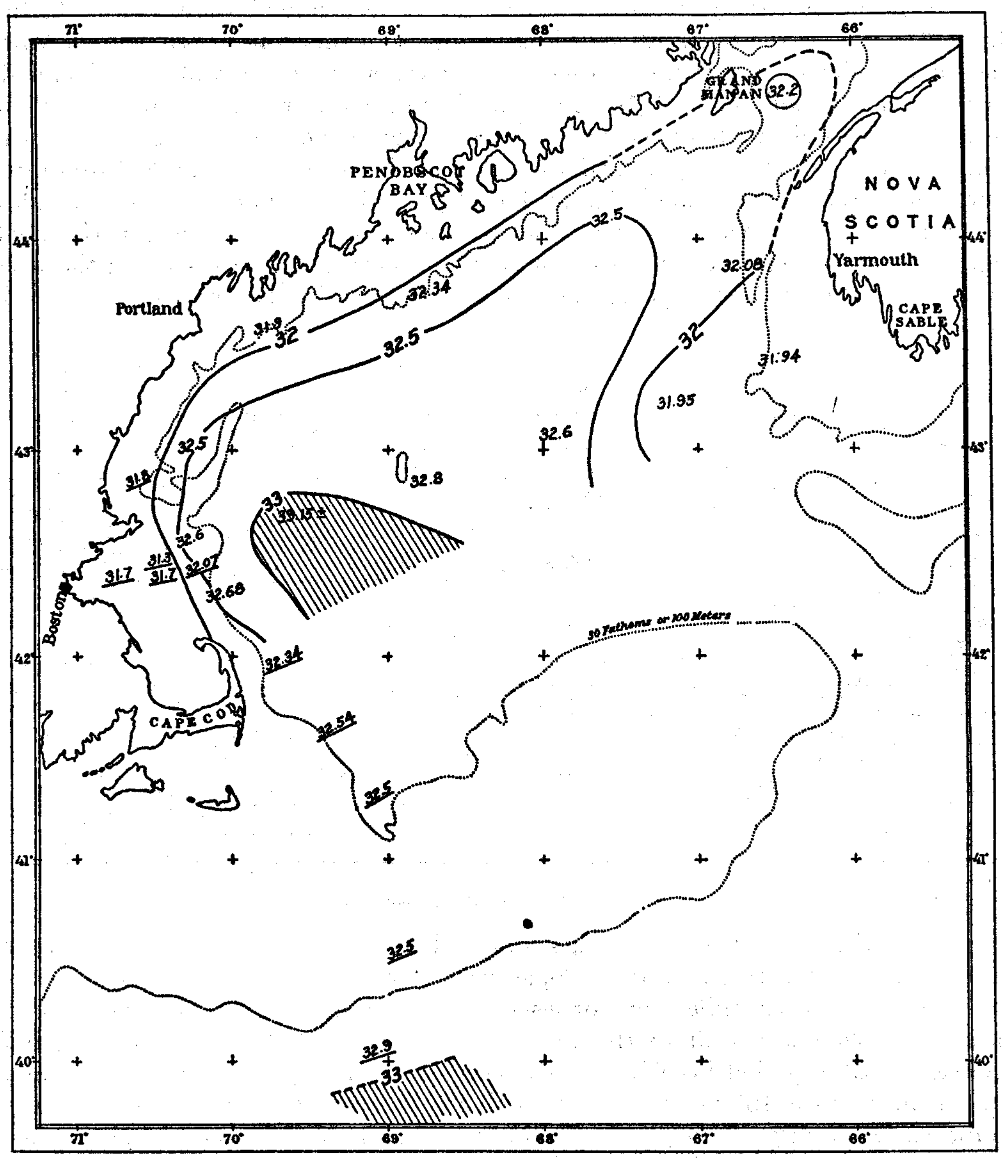

FIG. 125.—Salinity at a depth of 40 meters, May 4 to 14, 1915 (plain figures), combined with May 4 to 17, 1920 (underlined figures). The encircled figure in the Bay of Fundy is for May 4, 1917, from Mavor (1923). Dotted curves are assumed

Apparently this drift was still in operation at the date of our May cruise in 1915 (the 4th to the 10th). Had it not been, and had absorption of the water of low salinity from the east into the general circulation been well advanced, the transition from salinities lower than 32 per mille in the east to 32.6 to 32.8 per mille in the center of the gulf would hardly have been as abrupt as we actually found it (figs. 125 and 126). Therefore, the salinities prevailing at the time were not reminiscent of some preceding event (as is too often the case), but evidence of a present state of circulation.

The isohaline for 32 per mille reached the eastern side of the basin at the time (fig. 126); and as the *Grampus* sailed eastward from this station (10270) on May 6 she did actually stem a current flowing westward with considerable velocity, as described in a later chapter (p. 917). In fact, it is unusual for the distribution of salinity to accord as closely with direct navigational observation of a surface current as happened on this occasion. The profiles for 1919 also show this Nova Scotian drift (outlined in this case by the isohaline for 32 per mille) reaching the eastern side of the basin, but no farther, at the beginning of May and again at the end of the month (fig. 121), in each case wedge-shaped in longitudinal section and involving the whole upper 100 meters on the slope of German Bank, but thinning out to nothing at its western edge.

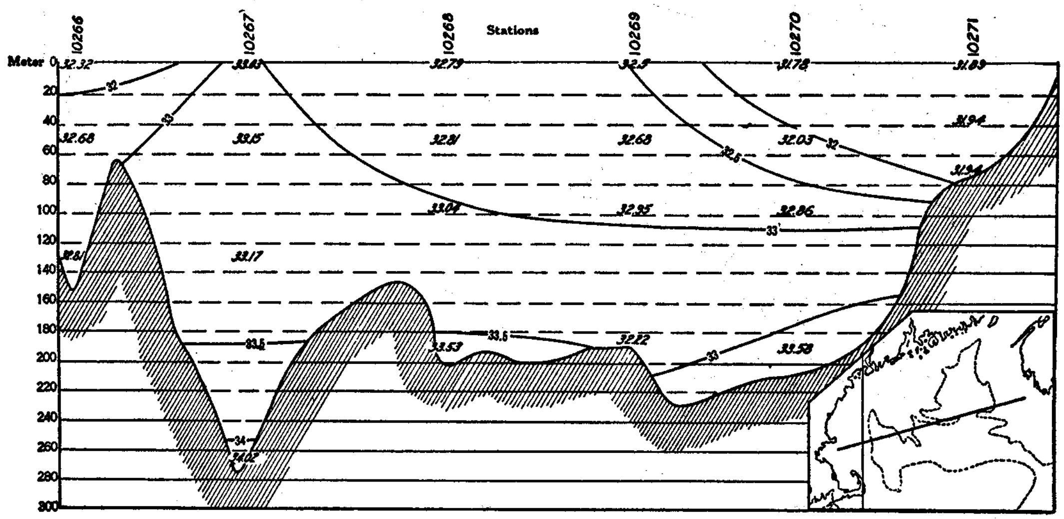

FIG. 126.—Salinity profile running eastward from the mouth of Massachusetts Bay to German Bank, May 4 to 7, 1915

If the May charts for 1915 (figs. 125 and 127) represent the normal seasonal succession to the April charts for 1920, as close correspondence in 1919 makes likely, an increase of 0.5 per mille (more or less) may be expected in the western side of the basin from the one month to the next at the 40-meter level, contrasting with the decrease in salinity that involves the whole coastwise zone, and an increase of about 0.2 per mille at the 100-meter level, though the precise magnitude of this change no doubt varies from year to year. This is reflected at the 40-meter level, just as at the surface, by a shift of the most saline center across the basin of the gulf from east to west (cf. fig. 115 with 125), as well as by the development of a mass of water of high salinity in the upper 100 meters in the offing of Massachusetts Bay, illustrated in profile (figs. 121 and 126).

This slight increase in salinity in the western side of the basin, coupled with the freshening of the eastern side for which the Nova Scotian current is responsible, tends to equalize the regional inequalities in the mid levels of the gulf (fig. 127) as the spring draws to a close. Thus, the extreme range of salinity in the gulf was little more than half as wide at 100 meters in May, whether of 1915 or of 1920 (about 0.7 per mille, fig. 127), than in April or in March of 1920 (respectively, 1.1

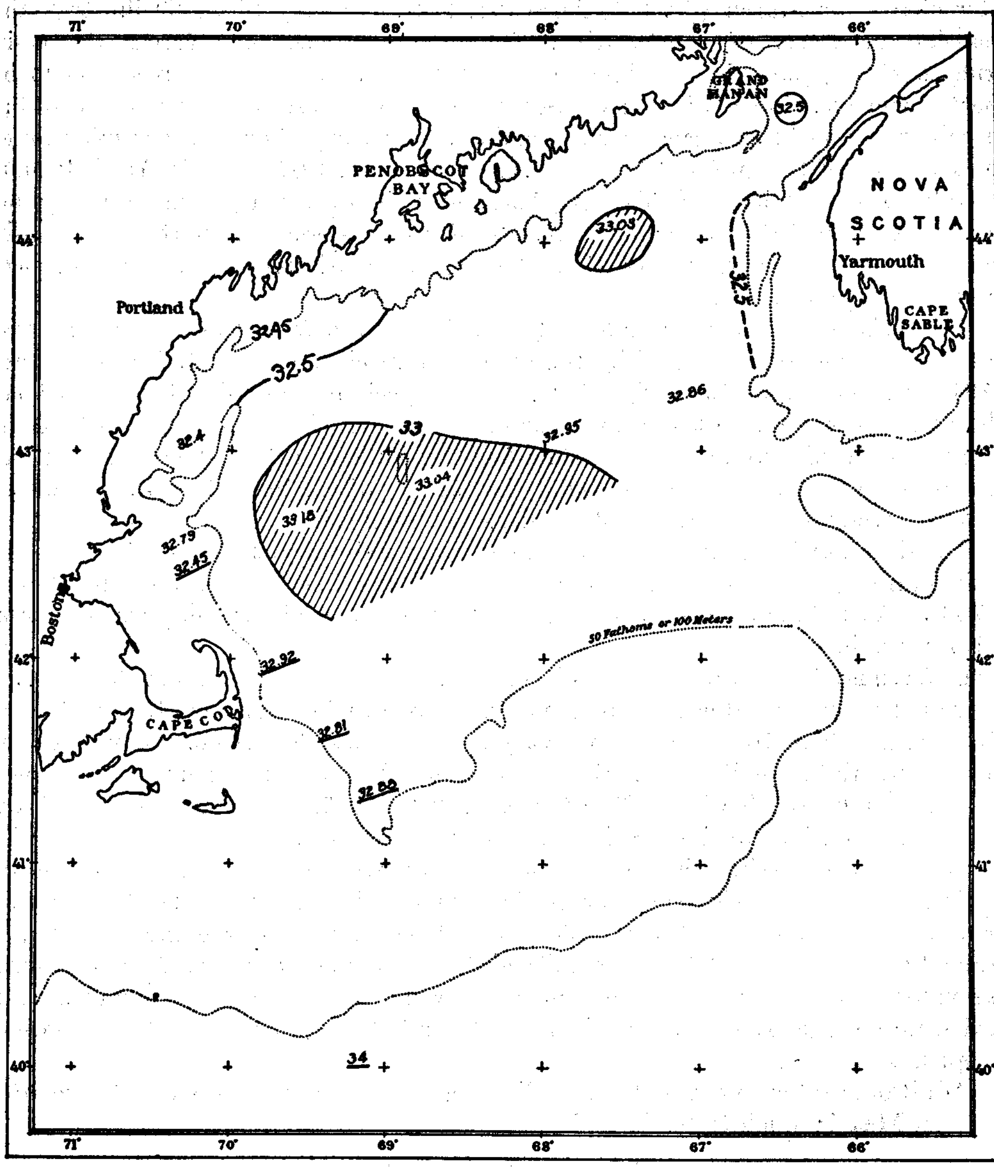

FIG. 127.—Salinity at a depth of 100 meters, May 4 to 14, 1915 (plain figures), combined with May 4 to 17, 1920 (underlined figures). The encircled figure in the Bay of Fundy is for May 4, 1917, from Mavor (1923)

and 1.3 per mille, figs. 94 and 116). At 175 meters (chosen as representative of the deep water of the gulf because this particular contour best outlines the trough of its basin) the extreme range of salinity was only 0.5 per mille (32.94 to 33.46 per mille) for the northern side during the first half of May, 1915—i. e., less than half the regional variation recorded there for March and April of 1920 (32.91 to 34.1 per mille).

The locations of the isohalines for 33 per mille from month to month on the 100-meter charts for March (fig. 94), April (fig. 116), and May (fig. 127) illustrate the expansion of water of comparatively high salinity westward across the basin during a strong pulse in the inflowing bottom current, and the recession to be expected when the indraft is weak. Some change of this sort is consistent with the general progress of the vernal cycle. Salinity averaging about 0.6 per mille lower over the basin of the gulf at 175 to 200 meters in May, 1915, than in April, 1920, is probably to be explained on this same basis; but the observations taken by the Ice Patrol cutter in 1919, when the salinity of the east–central part of the basin increased through May, proves that the indraft continues active right through the month in some years.

The differences that may be expected in this respect from one May to the next are more graphically illustrated by the west–east profiles of the gulf for that month of 1915 (fig. 126) and 1919 (fig. 121). Note especially the thick band of 34 per mille water on bottom in the latter year in the eastern side of the gulf, where the value was only slightly more saline than 33.5 per mille in 1915. The fact that this is the only month when we have found the salinity of the basin lowest, as a whole, in the eastern side, not in the western, deserves emphasis.

The decrease in salinity that took place from February, 1920, to May over the continental slope to the southwest of Georges Bank has already been mentioned (p. 750). At 100 meters the May value (station 20129, ±34 per mille) was the lower by 1.3 per mille.

Unfortunately no water samples have been collected in May along the 400-mile sector of the continental edge from the offing of Nantucket eastward to the offing of Sable Island, where 100-meter values varying from 33.4 to 34.8 per mille have been reported by the Canadian Fisheries Expedition (Bjerkan, 1919; *Acadia* stations 9 and 10) and by the Ice Patrol[94] in the years 1914, 1915, and 1922, evidence of considerable fluctuations in the physical state of the slope water.

With the low values just stated, and values even lower at the same relative location off the eastern slope of Georges Bank in March and April, 1920 (32.8 to 33.46 per mille at 100 meters, stations 20068 and 20109), off Shelburne, Nova Scotia, on March 19 of that year (33.78 per mille at 100 meters, station 20077), it is evident that water of 35 per mille is usually separated from the slope by lower salinities eastward from Georges Bank to the tail of the Grand Banks during the third month of the spring.

Additional information as to the salinity along the seaward slope of the Scotian Banks in May is much to be desired.

SALINITY IN JUNE

A tendency toward progressive equalization is recorded from May to June as the overflow of the Nova Scotian current past Cape Sable and the outpourings of river waters are gradually incorporated into the gulf.

[94] Ice patrol station 29, May 17, 1914, 34.05 per mille at 200 meters; station 24, May 19, 1915, 33.66 per mille at about 100 meters; station 213, May 28, 1922, 34.79 per mille at 100 meters; see U. S. Coast Guard (1916) and Fries (1923).

In the year 1915 salinity was determined at 19 stations in June, sufficing to outline the regional and vertical distribution for the eastern side of the area and out across the shelf south of Cape Sable; while the *Fish Hawk* stations for 1925 extend the picture to Massachusetts Bay.

The most instructive feature of the surface chart for June, 1915 (fig. 128), is its demonstration that the drift of water of low salinity into the gulf from the east had slackened, if not entirely ceased, since mid May, the isohaline for 32 per mille having shifted 50 miles or so eastward from the location it occupied six weeks earlier (fig. 120), the salinity of this side of the basin having increased from 31.78 per mille to 32.25 per mille during the interval. While the Nova Scotian drift may have extended to the eastern parts of Georges Bank in May (p. 745), an abrupt transition along

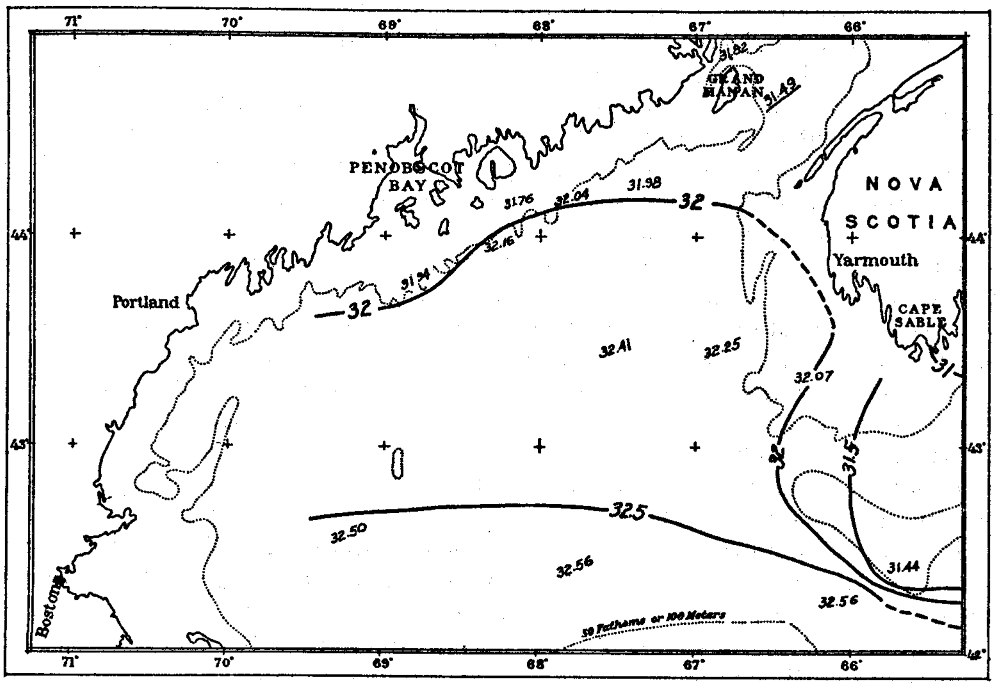

FIG. 128.—Surface salinity of the eastern and central parts of the Gulf of Maine, June, 1915

the eastern side of the Eastern Channel in June, from low values over Browns Bank (31.5 per mille) to higher ones farther west, shows that it had ceased to expand in this direction by that time.

The incorporation of river water, which is responsible for vernal freshening of the coastal belt, was reflected in 1915 by an average increase of 0.2 to 0.5 per mille in surface salinity along the northern margin of the gulf from May (fig. 120) to June (fig. 128, values ranging from 31.8 to 32.2 per mille).

Within the Bay of Fundy, where the effects of the freshets from the St. John River are responsible for a very sudden freshening of the surface from April to May, as described above (p. 743), the recovery is correspondingly more rapid than in the open gulf, where the influence of any one river is spread over a wider area. In 1917, for example, the salinity of the surface water between Grand Manan and Nova

Scotia rose from 27.9 per mille on May 4, to 31.49 per mille on June 15 (Mavor, 1923, p. 375); and some such succession may be expected close in to the mouth of any one of the large rivers that drain into the gulf.

No observations were taken in the western side of the gulf in June, 1915; but the *Fish Hawk* stations for 1925 (figs. 129 and 130) show a similar increase of about 0.7 per mille in the surface salinity of Massachusetts Bay, from a mean of 31.57 per mille on May 20 to 22 to a mean of 32.28 per mille on June 16 to 17, with no evidence of the drift of water of low salinity into the bay from the north past Cape Ann, which the isohaline for 31.5 per mille made apparent three weeks earlier (fig. 119).

Contrasting with the general rise in surface salinity that takes place alongshore and over the eastern side of the basin from May to June, as just described, the charts for 1915 (figs. 120 and 128) show a corresponding freshening of the surface over the western side of the basin, resulting from the general dispersal of land water out to sea combined with a cessation of the upwelling that was taking place there in May (p. 746). In that particular year the actual decrease off Cape Ann was from 33 per mille on May 5 (station 10267) to 32.5 per mille on June 26 (station 10299)—evidence of the gradual tendency toward the equalization that follows the temporary freshening or salting of any part of the gulf.

I can say nothing of salinity over Georges Bank or for Nantucket Shoals in June; data there for that month are desiderata.

Although no notable alteration takes place in the vertical distribution of salinity from May to June, the following minor changes are worth attention:

The western branch of the basin, off Cape Ann (fig. 112), freshens notably from the one month to the next in the upper 40 to 50 meters, but salts at depths greater than 120 meters, resulting in a considerably wider range of salinity between surface and bottom, a change important because of the greater vertical stability it gives to the column of water as a whole.

It is doubtful, however, whether any seasonal alteration of this order extends to the southeastern part of the basin, because the salinity of the upper 50 to 60 meters was almost precisely the same there on June 25, 1915 (station 10298), as it was two months earlier in the season in 1920 (station 20112, April 12); and while the June station was slightly the salter of the pair at 100 meters, it was slightly the fresher from 150 meters downward to the bottom. In the eastern side of the basin, too, the vertical range of salinity decreases from May to June, instead of increasing, as the Nova Scotian current slackens. The whole column of water over German Bank was likewise (and for the same reason) about 0.2 per mille more saline on June 19 (station 10290, about 32.1 per mille) than it had been on May 7 (station 10271), though as nearly homogeneous vertically, a condition maintained here the year round by active tidal stirrings.

In the Bay of Fundy, between Grand Manan and Nova Scotia, Mavor (1923, p. 375) found much less spread between surface and bottom on June 15, 1917, than on May 4, consequent on the considerable salting of the upper stratum just described (p. 755); and the contrast between the moderately wide vertical range of salinity there, as well as at our own station at the mouth of the bay on June 10, 1915 (station 10282), and the vertical homogeneity of the water of the Grand Manan

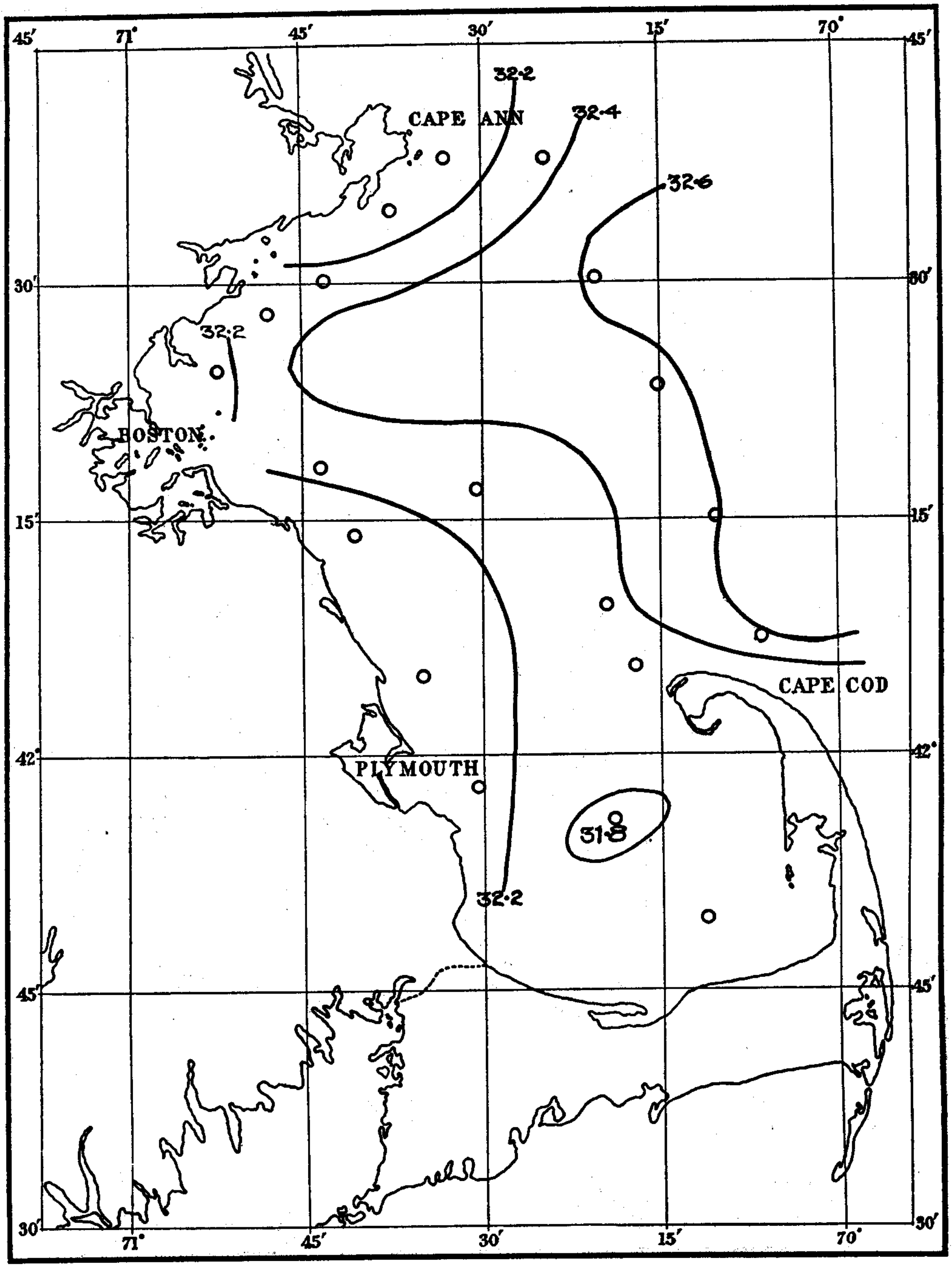

FIG. 129.—Salinity of Massachusetts Bay at the surface, June 16 to 17, 1925

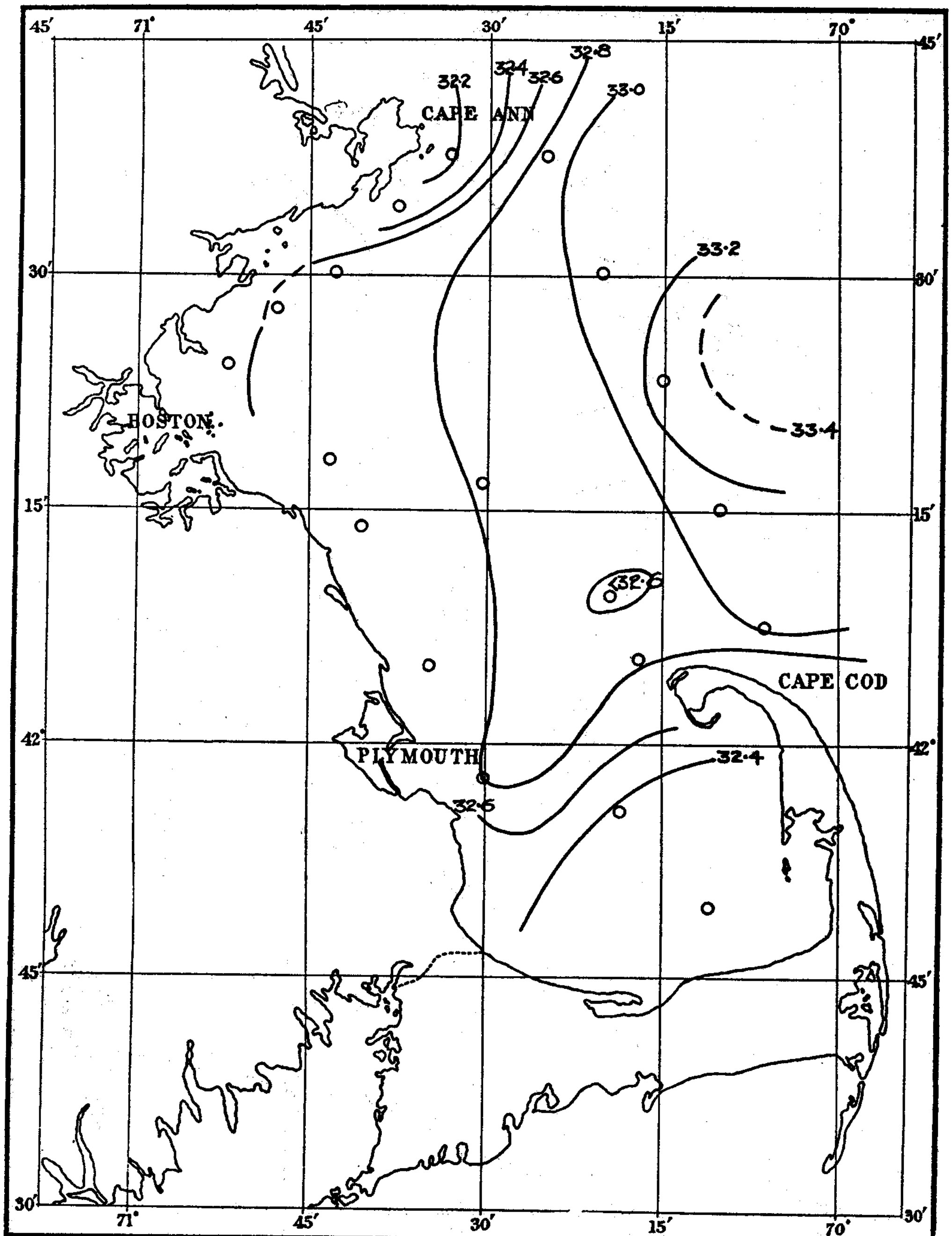

FIG 130.—Salinity of Massachusetts Bay at 20 meters, June 16 to 17 1925

Channel on the 4th (station 10281, 31.8 per mille from surface to bottom), is an interesting illustration of the local differences to be expected at neighboring stations in these tide-swept waters.

Near Mount Desert, too, observations taken at three stations on June 11 to 14, 1915 (stations 10284, 10285, and 10286), show much less difference between surface and bottom than on May 10 and 11 (stations 10274 and 10275), the surface having salted by about 0.5 per mille in the interval, but the bottom by not more

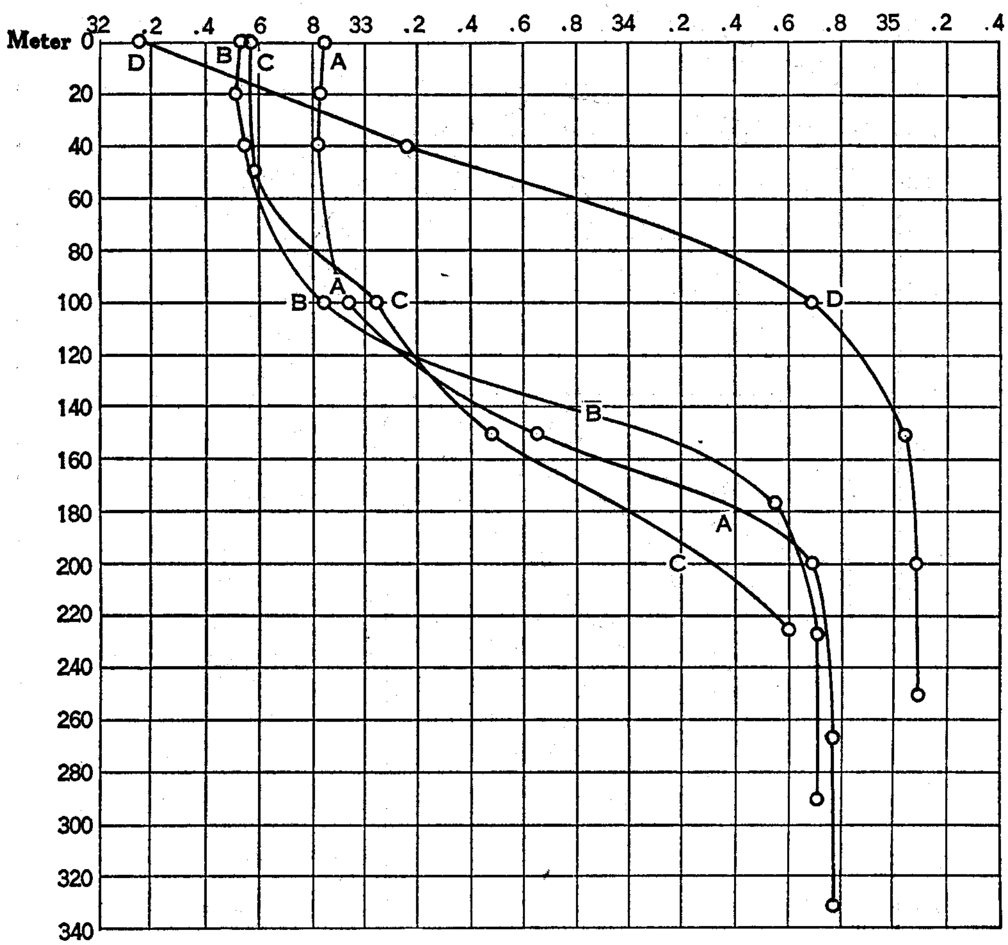

FIG. 131.—Vertical distribution of salinity in the southeastern part of the basin of the gulf. A, March, 1920 (station 20064); B, April, 1920 (station 20112); C, June, 1915 (station 10298); D, July, 1914 (station 10225)

than 0.2 per mille. Off the mouth of Penobscot Bay, however, near the 100-meter contour, no appreciable change took place in the salinity at any depth from May 12, 1915 (station 10276), to June 14 (station 10287).

In Massachusetts Bay, which receives very little river water from its own coast line, the *Fish Hawk* cruises of 1925 showed an increase in salinity, surface to bottom, between the 20th of May (cruise 13) and the middle of June, averaging about 0.7 per mille for all the stations and levels combined, with a maximum change of 1.3 per

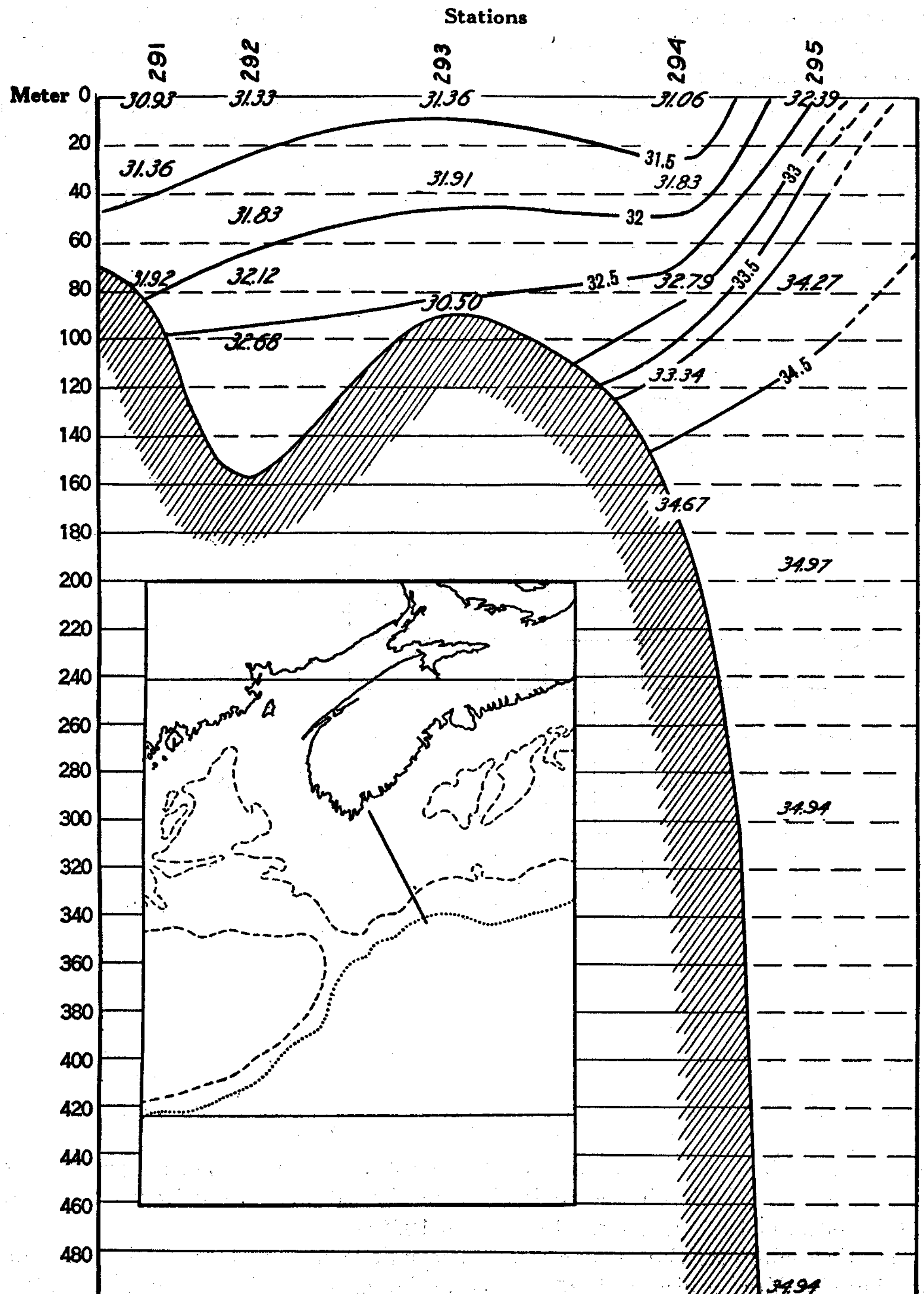

FIG. 132.—Salinity profile running southeastward from the offing of Shelburne, Nova Scotia, to the continental slope, June 23 to 24, 1915 (stations 10291 to 10295) Bottom value at station 10293 should read 32.50

mille, a minimum of 0.1 per mille. This salting was greatest (0.7 to 0.8 per mille for the whole column) across the mouth of the bay (stations 30 to 34) and inward over its deep central part (stations 18A and 3), consistent with the fact that the source for any change of this order must lie in the still higher salinities of the deep water of the basin in the offing. In spite of small local variations, however, which are always to be expected from station to station near shore, depending partly on the stage of the tide when the observations are taken, the average difference in salinity between the surface of the bay and the 40-meter level was almost precisely the same on the June cruise (0.7 per mille) as it had been three weeks earlier in the season.

The June stations (fig. 132) on the continental shelf off Shelburne, Nova Scotia (10291 to 10295), though outside the geographic limits of the gulf, strictly construed,

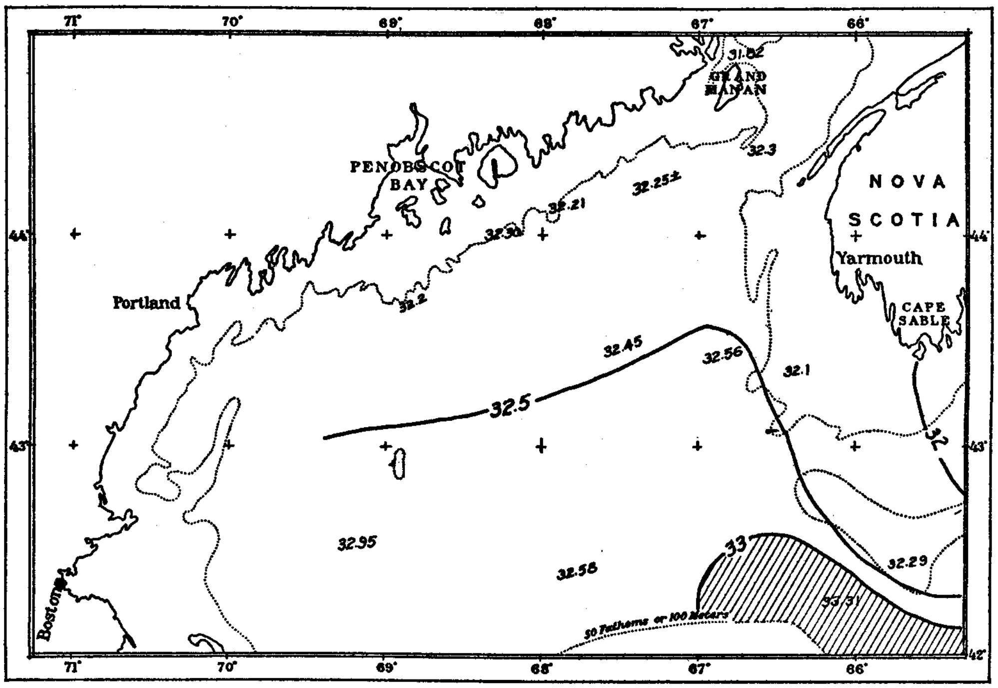

FIG. 133.—Salinity at a depth of 40 meters, last half of June, 1915

are interesting in this connection as affording a cross section of the westward extremity of the Nova Scotian current at the time. Here the vertical range of salinity was wider than anywhere in the Gulf of Maine in that month, with values comparatively uniform, depth for depth, over the shelf but considerably higher outside the 100-meter contour (station 10295).

Horizontal projections give a more graphic spacial picture of the seasonal alterations just stated. At the 40-meter level the relationship between May (fig. 125) and June (fig. 133) is much the same as at the surface (p. 756)—the eastern side of the gulf salter than in May, the western and northern sides of the basin less so, as reflected by a translation of the isohaline for 32.5 per mille well out into the basin from the position close to the coast of Maine, which it had previously occupied.

Although no considerable shift of this particular isohaline is indicated off Massachusetts Bay by the data for 1925 (*Fish Hawk* cruise 14), the 40-meter level was more nearly uniform in salinity there that June (32.6 to 33.4 per mille) than it had been the month before.

At greater depths in the gulf (as illustrated by the 100-meter level), which are but slightly affected by the spring freshets from the rivers or by the Nova Scotian current, the mean salinity increased by about 0.2 per mille in the eastern side of the basin from May (fig. 127) to June (fig. 134) in 1915, but continued almost constant in the western side. Mavor (1923) has also recorded an increase in the salinity of the deep water of the Bay of Fundy during this same period, from 32.5 per mille at 100 meters on May 4, 1917, to 32.7 per mille on June 15. A change of the

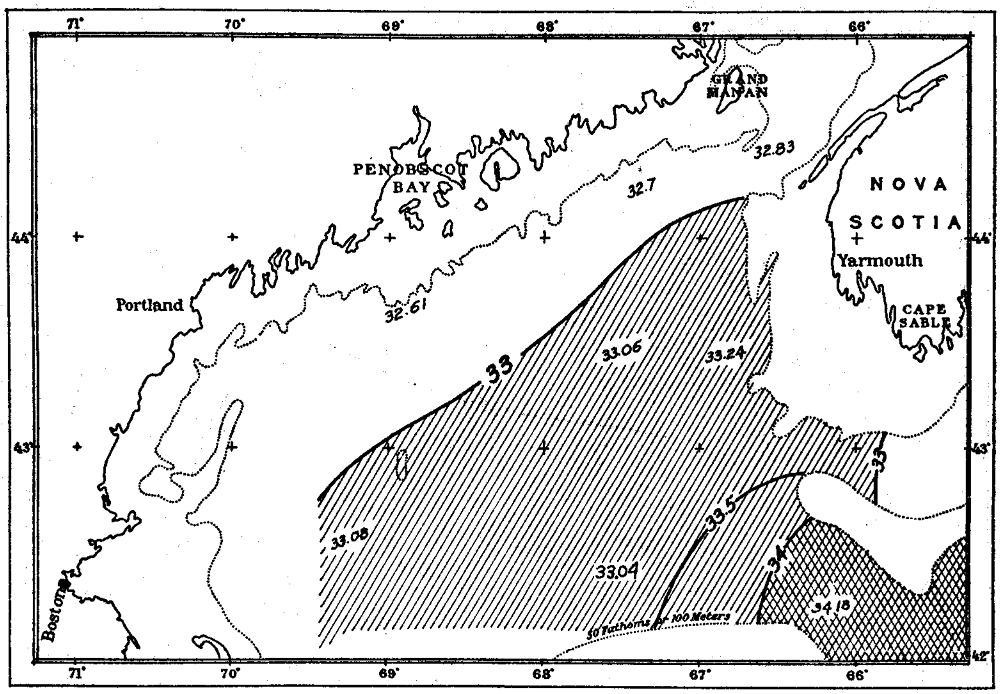

FIG. 134.—Salinity at a depth of 100 meters, last half of June, 1915

same sort was registered in the bottom of the open basin, as illustrated by the following tables:

Salinities (per mille) at 175 meters

Date	Northeastern corner	Easternside	Southeastern part	Eastern Channel	Western basin	Center
March, 1920	33.78	34.04	34.20	34.53	33.82	33.08
April, 1920	34.02	34.30	34.56	34.60	33.84	34.18
May, 1915	33.40	33.46			33.37	33.45
June, 1915	33.60	33.64	34.00	34.80	33.55	33.50

Salinity on the bottom of the trough, June, 1915.

Locality	Depth	Salinity	Locality	Depth	Salinity
	Meters	*Per mille*		*Meters*	*Per mille*
Fundy Deep, station 10282	180	33.06	Eastern Channel, station 10297	275	34.92
Northeastern corner, station 10283	180	33.66	Southeastern corner, station 10298	225	34.60
Eastern basin, station 10288	220	33.95	Western basin, station 10299	210	33.82

The fact that the whole trough of the gulf was nearly as saline in the last half of June, 1915, as we found it in April, 1920 (p. 737), suggests a recovery of the indraft of slope water during the last half of May and first days of summer; but if such a recovery actually took place in 1915 it seems soon to have slackened again, judging from the rather abrupt transition from higher salinities in the Eastern Channe to lower ones just within the basin of the gulf recorded during the third week of that June (see the preceding tables).

The expansions and contractions of 34 per mille water over the floor of the gulf, and the depth at which its upper limit lies below the surface of the water at any given time, more clearly reflect the recent activity of the indraft through the Eastern Channel than does the distribution of salinity at any given level in the water. In April, 1920, water as salt as this flooded the bottom of both arms of the basin, rising up to within about 140 to 175 meters of the surface along the eastern slope of the gulf (fig. 118). In June, 1915, however, 34 per mille water was confined to the southeastern corner of the basin (station 10298) close to the entrance of the Eastern Channel.

SALINITY IN JULY AND AUGUST

SURFACE

If the readings taken in the western side of the gulf in July of 1912, 1913, and 1916 represent the normal succession to the June state of 1915 and 1925 (just described), the surface of this part of the area suffers a second freshening from 32 to 32.5 per mille in June to 31.4 to 31.9 per mille in July, but with little or no change from the one month to the next along the coast of Maine (31.5 to 31.8 per mille in July as well as in June). If this represents the regular seasonal progression it probably reflects the anticlockwise surface drift, carrying the discharges of the eastern rivers around the gulf to the Massachusetts Bay region a month or more after their freshening effect has been entirely obscured off the coast of Maine by tidal stirrings. This explanation is supported by the fact that the July values for the surface of the bay were lowest in 1916 (30.5 to 31.2 per mille), when a very tardy spring, with unusually heavy snowfall, would make a seasonal sucession of this sort the most likely. The surface water of the western part of the basin of the gulf, in the offing of Cape Ann, has proved less saline in every August of record (1913, 1914, and 1915) than it is in May (p. 741) or June (p. 756), in the following seasonal sequence and for the same reason:

Surface salinity, western basin

Date	Station	Salinity	Date	Station	Salinity
		Per mille			*Per mille*
May 4, 1915	10267	33.03	Aug. 9, 1913	10088	32.21
June 26, 1915	10299	32.50	Aug. 22, 1914	10254	31.55
July 15, 1912	10007	31.62	Aug. 31, 1915	10307	32.47

The exact date when this side of the basin is least saline varies from year to year, likewise the minimum value to which the salinity of the surface falls there, our experience up to date suggesting 31.5 to 32.2 per mille as usual at its lowest. In the same way the freshening recorded by Mavor (1923) in the Bay of Fundy early in the summer of 1917 may reflect the transference of the water of low salinity from the Nova Scotian current northward along the eastern side of the gulf, following the route of many of our drift bottles (p. 895).

Apart from this question, the most interesting aspect of the late summer data for the inner parts of the gulf is the comparative uniformity prevailing at the surface all along the coastal belt from Massachusetts Bay to Grand Manan in 1912 and 1915 (31 to 31.9 per mille). It is probable that the isohaline for 32 per mille usually crosses outside the mouth of the Bay of Fundy in July, because Vachon (1918) and Mavor (1923) record surface salinities ranging from 30.36 to 31.48 per mille at various localities in Passamaquoddy Bay and off Grand Manan for that month in 1916; 30.61 per mille at *Prince* station 3, east of Grand Manan, on July 4, 1917; rising to 31.22 per mille there on July 31.[95]

A considerable body of data has been gathered in the open gulf for the last half of July and for the month of August in the years 1912, 1913, 1914, 1915, and 1922, which, with the determinations for the Bay of Fundy for the summers of 1914, 1917, and 1919 (Craigie, 1916b; Vachon, 1918; and Mavor, 1923) afford a picture of the normal midsummer state of the surface of the gulf, with some indication of the annual fluctuations to which it is subject.

For salinity, as for temperature, the period, July to August, is the most nearly static part of the year in the open gulf, a statement supported by the following surface readings at pairs of stations at proximate localities but taken several weeks apart.

Locality	Date	Station	Salinity
			Per mille
Near Gloucester	July 12, 1912	10005	31.67
Do	Aug. 31, 1912	10046	31.67
Off northern extremity of Cape Cod	July 8, 1913	10057	31.90
Do	Aug. 9, 1913	10087	32.09
Southwest part of basin	July 19, 1914	10214	31.80
Do	Aug. 23, 1914	10256	31.80
Near Cape Sable	July 25, 1914	10230	31.47
Do	Aug. 11, 1914	10243	31.67
Off Grand Manan (Prince station 3)	[a] July 4, 1917		30.61
Do	[a] July 31, 1917		31.22
Near Mount Desert Island	July 19, 1915	10302	31.83
Do	Aug. 18, 1915	10305	31.94
Off Penobscot Bay	Aug. 2, 1912	10021	32.43
Do	Aug. 21, 1912	10038	32.32
Near Isles of Shoals	July 22, 1912	10012b	31.92
Do	Aug. 24, 1912	10041	32.07
Eastern side of basin	June 19, 1915	10288	32.41
Do	Sept. 1, 1915	10309	32.47
Western side of basin	June 26, 1915	10299	32.50
Do	Aug. 31, 1915	10307	32.47
Near Nantucket Shoals lightship	July 9, 1913	10060	32.63
Do	[b] Aug. 8, 1913		32.77

[a] Mavor, 1923. [b] Captain McFarland.

[95] Surface densities, determined from hydrometer readings in the Bay of Fundy region, also indicate salinities ranging from 30.7 per mille to 32.7 per mille (Copeland, 1912; Craigie and Chase, 1918).

The maximum alteration that took place in the surface salinity at any one of these localities during the interval of from three to nine weeks was thus only 0.6 per mille; in most cases it was less than 0.2 per mille; several times it was too small to be measured, a statement covering both sides of the basin of the gulf as well as the coastal belt, and applying to one locality or another in three different years. Among the islands or off headlands where the tide runs strong the surface would not show this uniformity, because the salinity in such situations varies widely with the stage of the tide. Even if the observations were taken at the same stage of tide, variation would be expected with the varying interaction between current and wind. Upwellings, for instance, such as follow offshore winds (p. 588), will bring up water appreciably salter, as well as colder, from below, along the western shores of the Gulf of Maine, even if the updraft comes from a depth of only a few meters.

It is probable that the high salinity of the surface stratum recorded near Gloucester on July 9, 1912 (station 10001, 32 per mille) is to be explained on this basis. The salinity of the whole upper 40 meters, or so, of water may, in fact, be expected to vary considerably along the northern shore of the bay within brief periods, depending on the direction of the wind as this drives the surface water onshore or offshore. Unfortunately, however, our observations do not throw much light on the fluctuations in salinity of this sort, except on one occasion at a locality 3 to 5 miles off Gloucester, where the surface salinity, as calculated from hydrometer readings,[96] increased by about 0.7 per mille between July 9 and 11 in 1912, with a corresponding decrease of 4.5° in surface temperature, the latter usually a sure evidence of upwelling thereabouts. In the eastern parts of the gulf, however, where the water is more nearly homogeneous vertically, winds and tides affect the surface salinity chiefly by the on and off shore interchange of salter and less saline waters. Copeland (1912), for example, found the salinity of Passamaquoddy Bay varying with the tide (as well as locally in the bay) according to the relative outflow from the St. Croix River. Swirling tidal currents are also partly responsible for the regional variations recorded by Vachon (1918) and by Mavor (1923) in the surface salinity of Passamaquoddy Bay and of the Bay of Fundy, where, however, they also record a general increase in surface salinity during July and August, as follows:

Locality	Date	Salinity	Locality	Date	Salinity
		Per mille			*Per mille*
Friar Roads	July 25, 1916	31.48	Bay of Fundy, off Grand Manan, Prince station 3	Sept. 4, 1917	31.92
Do	Aug. 2, 1916	31.27	Passamaquoddy Bay, Prince station 4	July 20, 1916	30.36
Do	Aug. 19, 1916	31.73	Do	July 27, 1916	28.97
Do	Aug. 31, 1916	31.84	Do	Aug. 3, 1916	30.27
Bay of Fundy, off Grand Manan, Prince station 3	July 24, 1916	30.43	Do	Aug. 10, 1916	30.19
Do	Aug. 25, 1916	31.77	Do	Aug. 17, 1916	30.58
Do	July 4, 1917	30.61	Do	Aug. 31, 1916	30.77
Do	July 31, 1917	31.22			

In every August of record—1912 (Bigelow, 1914, pl. 2), 1913 (fig. 135), 1914 (fig. 136), or 1915 (fig. 137)—the surface salinity has been highest over the north-

[96] Both taken with the same instrument

eastern part of the basin of the gulf, with the maximum near Lurcher Shoal in 1912 and 1915, over the northeastern deep as a whole and over German Bank in 1913, off Machias, Me., and on German Bank in 1914. Furthermore, the maximum reading for the month has varied little from year to year—32.84 per mille in 1912 (station

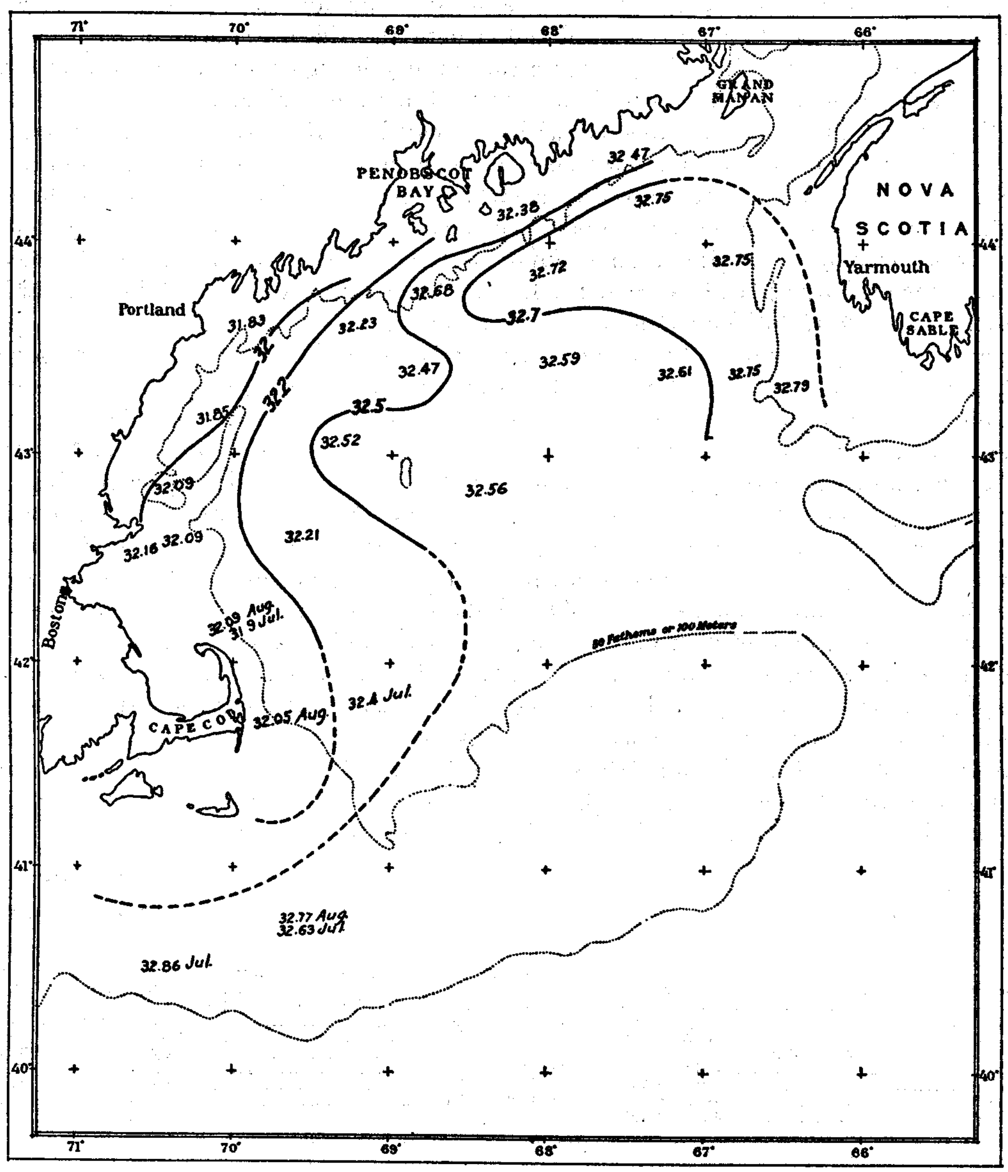

FIG. 135.—Salinity at the surface, August, 1913

10031), 32.75 to 32.79 per mille in 1913 (stations 10094 to 10097), and 33.06 per mille in 1914.

A certain consistency also appears from year to year in the outlines of the area occupied by water salter than 32.5 or 32.7 per mille. In 1913 and 1914 this took the form of a U or V, its concavity directed toward the southwest, its one arm roughly paralleling and somewhat overlapping the 100-meter contour off the Nova Scotia coast, its other arm similarly paralleling the coast of Maine westward as far as the offing of Penobscot Bay (figs. 135 and 136). In my account of the salini-

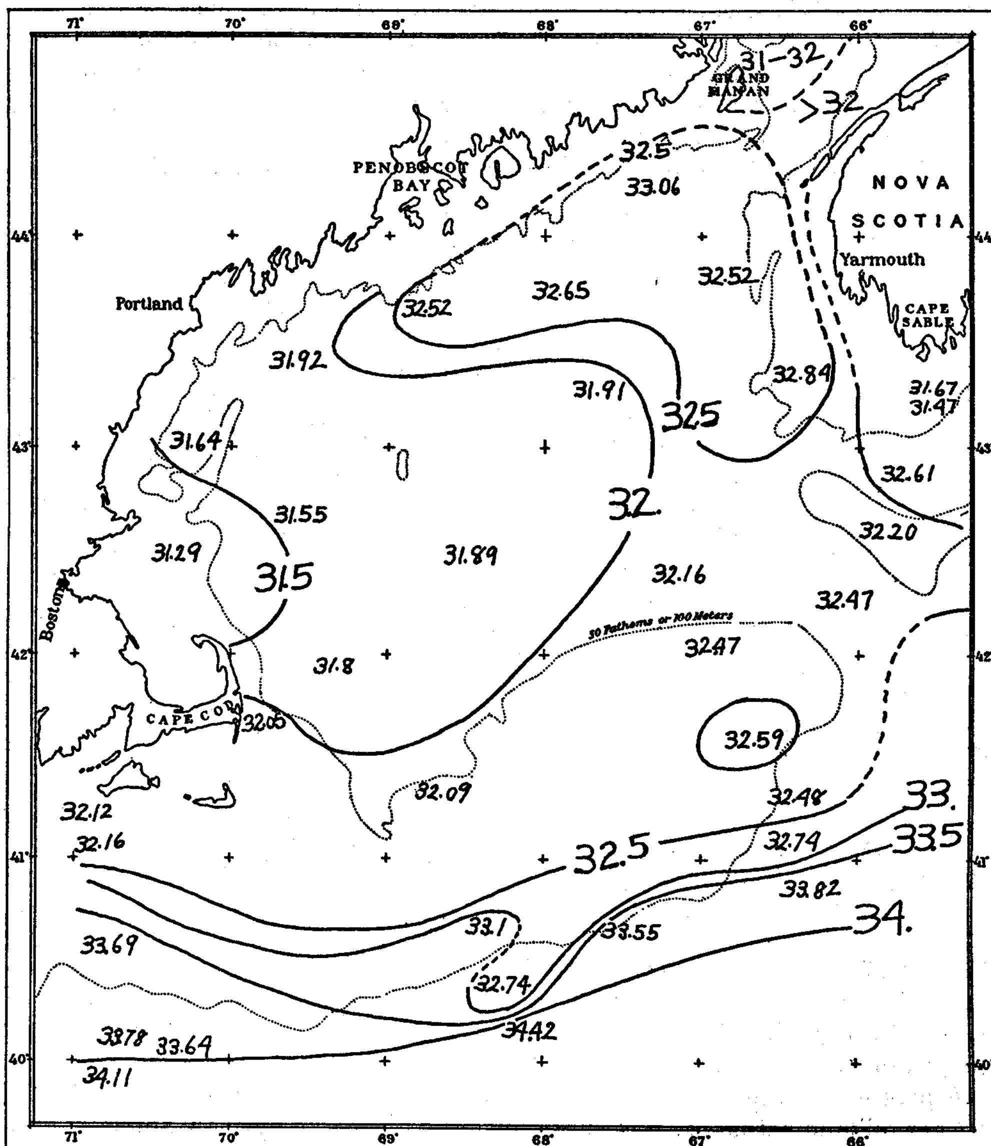

FIG. 136.—Salinity at the surface, July to August, 1914. For 32.61 in the northern channel read 32.01

ties of 1913 I assumed that this saltest tongue was continuous with the still higher salinities outside the continental shelf via the southeastern part of the gulf (Bigelow, 1915, pl. 2). However, continued investigation of the gulf has made it more likely that this was actually an isolated pool surrounded by less saline water on the south, as was certainly the case in July and August, 1914 (fig. 136). This was again the case during August and the first few days of September in 1915 (fig. 137), when the surface was less saline than 32.5 per mille at all the eastern stations on the line Cashes Bank-Cape Sable, but more saline (32.6 to 32.8 per mille) farther north in the eastern arm of the basin.

Unfortunately, the stations for 1915 were not situated close enough together to locate the course of the isohaline for 32.5 per mille in a satisfactory manner; in the preliminary account of the operations for that season a reading of 32.52 per mille near Cashes Ledge (station 10308), with slightly lower salinities to the west of it as well as to the east (32.47 per mille at stations 20307 and 20309), was taken as evidence of a body of still salter water in the southern half of the gulf (Bigelow, 1917,

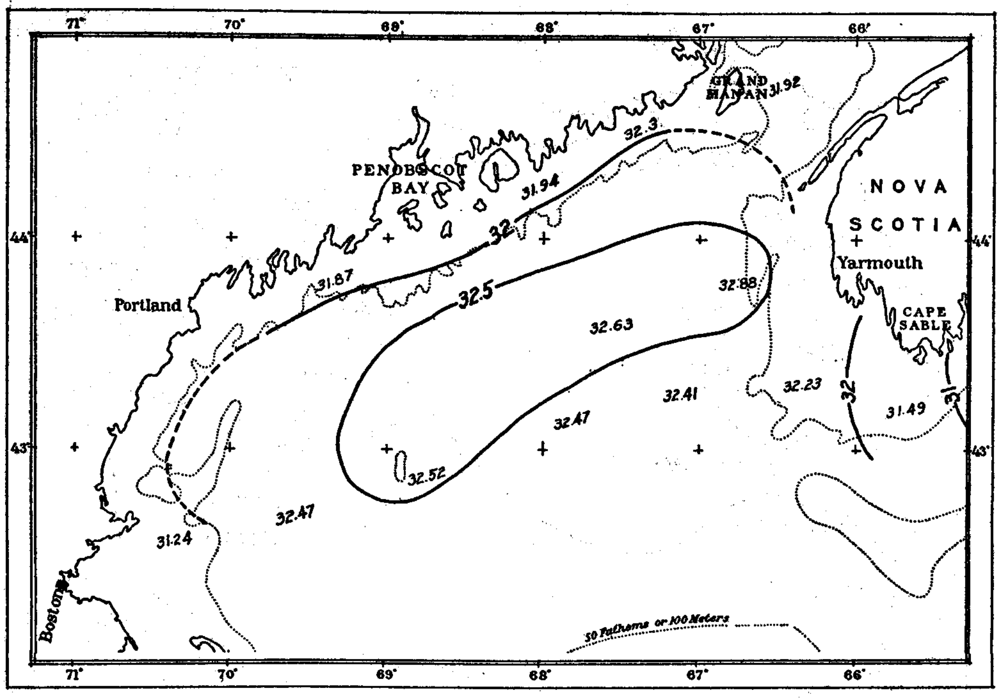

FIG. 137.—Salinity at the surface, August to September, 1915

p. 222, fig. 67). Further study of the salinities for the several years combined makes it more probable that the station in question marked the southwestern extremity of a band of 32.5 per mille that continued thence to the vicinity of Lurcher Shoal, as is indicated on the chart (fig. 137).

A pool more saline than the surrounding water and usually very close to 32.75 to 33 per mille in actual salinity, may thus be expected to develop annually on the surface over the northeastern corner of the basin in August, its boundaries conforming more or less closely to the contour of the coastal slopes of Maine and of Nova Scotia but not involving the Bay of Fundy at all. Being entirely surrounded (in most summers, at least) by less saline water on the offshore as well as on the inshore side, it must obviously have its source in the still higher salinities below the surface as water is brought up by vertical currents of some sort, not in any direct indraft from offshore.

This salt pool had no counterpart in June (fig. 128) or in May (fig. 120) of 1915, but much smaller phenomena of the same sort were recorded off Lurcher Shoal in April, 1920 (station 20101, 32.9 per mille), in the southeastern part of the gulf and in the eastern part in that March (fig. 91). Thus, following the freshening characteristic of May (p. 745), the eastern side of the surface of the gulf is once more as salt by the end of August as at any time during the early spring.

Much lower values prevail along the west Nova Scotian shore all summer, Vachon (1918) having recorded 31.34 to 32.09 per mille on a line from Brier Island to Yarmouth on September 7, 1916, with readings of 31.17 per mille at high tide, 31.12 per mille at low tide, in Yarmouth Harbor on the 8th. It is on the strength of his data that the isohaline for 32 per mille is represented on the August chart (fig. 136).

To the eastward of Cape Sable the water next the coast is still less saline (31.7 to 31.6 per mille) in summer, with rather an abrupt west-east transition from higher to lower values off the cape. Essentially this is the same regional distribution as in June, except that the successive isohalines shift to the eastward during the early summer as the Nova Scotian current loses head. The constancy of this Nova Scotian water from month to month and from year to year also deserves mention, the lowest values recorded in the offing of Shelburne (including Bjerkan's (1919) data) ranging only from 30.9 to 32.1 per mille for the months of March, June, July, and September of the years 1914, 1915, and 1920. Sometimes these lowest values have been close in to the land off Shelburne, as was the case in July, 1915 (Bjerkan, 1919), and in September of that year (fig. 137); sometimes farther out, with higher values next the coast, as in July, 1914, and in March, 1920 (p. 703); but no definite seasonal succession is yet established in this respect.

The narrow band of water less saline than 32 per mille, which probably skirts the western coast of Nova Scotia every summer, is separated from the equally low salinities (31.2 to 32 per mille) of the northern side of the Bay of Fundy by considerably more saline surface water (32.3 to 32.4 per mille) along the southern (Nova Scotian) shore of the latter; such, at least, was the case in the summers of 1916 (Vachon, 1918) and 1919 (Mavor, 1923).

In each midsummer of record (1912, 1913, 1914, 1915) we have found the least saline surface water as a narrow but continuous band skirting the coast of Maine, and so southward to the region of Massachusetts Bay, usually 31 to 32 per mille in actual value. Inside the outer islands, and in the estuaries, still lower surface salinities are to be expected locally (e. g., 30.61 per mille in the western entrance to Penobscot Bay, August 3, 1912, station 10021a), grading, of course, to brackish water in the mouths of rivers. The definite boundary of this coastal water of low salinity (32 per mille) can not be laid down along the coasts of Maine and Nova Scotia on the chart for August, 1914 (fig. 136), because most of our stations for that year were located outside the 100-meter contour. In this respect the chart for 1913 (fig. 135) is more instructive.

In the northwestern part of the gulf variations in the distribution of salinity from summer to summer show that the movements of the surface water are variable in detail.

Thus, in July and August, 1912, the isohaline for 32.4 per mille (the critical one in this particular summer) marked a definite expansion of coastal water off Penobscot Bay (Bigelow, 1914, pl. 2). In August, 1913 (fig. 135), the undulations of the isohaline for 32.5 per mille again suggested an anticlockwise swirl off the bay, drawing salter water into its northern and eastern sides, fresher water into its western and southern sides. In August, 1914 (fig. 136), the surface salinity of this part of the gulf was more uniform, with no evidence of any such outflow off the Penobscot; nor is anything of the sort indicated in the surface chart for 1915 (fig. 137).

In the Massachusetts Bay region, by contrast, the regional distribution of salinity at the surface has been more nearly constant from summer to summer. Thus, in August, 1922 (apparently a representative year in this respect), when the surface at 13 stations ranged from 30.95 to 31.29 per mille, the distribution was of the usual coastwise type—i. e., slightly lowest (30.9 to 31 per mille) close to Gloucester (station 10633), off the mouth of Boston Harbor (station 10638), and close to land in Cape Cod Bay (stations 10643 and 10644); uniformly slightly higher across the mouth of the bay (31.2 per mille at stations 10631 and 10632). Three stations on a line crossing the mouth of the bay on August 31, 1912, showed no greater variation than this on the surface, though all of them gave slightly higher readings (31.67 to 32.03 per mille). It is probable that the surface of the bay would have been found less saline than this in August, 1916, judging from a surface reading of 31.27 per mille off the tip of Cape Cod on the 29th (station 10398) and from the fact that the mouth of the bay had been only 30.5 to 31.2 per mille a month earlier (stations 10340 to 10342). In 1913 the August value was somewhat higher at the mouth of the bay—i. e., about 32.1 per mille.

Observations taken in the offing of Nantucket and on the northwestern part of Georges Bank in July of 1913, 1914, and 1916 show all this area included within the influence of the low salinity of the coastal belt, with surface values close to 32 per mille over Nantucket Shoals, rising to 32.1 to 32.5 per mille over the neighboring parts of Georges Bank (fig. 136; Bigelow, 1922, fig. 36). Surface readings make it probable that in July, 1914 (fig. 136), the band of low temperature described above (p. 608) as crossing the bank from northeast to southwest was reflected in an expansion of low salinity from the southwestern part of the bank out across its seaward slope, as outlined by the isohaline for 33 per mille.

It is probable that the regions of low surface temperature over the shoaler parts of Georges Bank, where the water is churned by strong tidal currents (p. 594), are equally characterized by a surface salinity higher than that of the general neighborhood. Our visits thither have afforded two instances that may be interpreted in this way—namely, a slightly higher value at one station on the eastern part (32.59 per mille at station 10223) on July 23, 1914, than at neighboring stations to the north, south, or east of it, and a value equally high on the western side on the same date of 1916 (station 10348, 32.54 per mille), again with slightly less saline surface water to the south, west, and apparently to the north. A similar pool of high surface salinity (presumably about 32.5 per mille) is also to be expected over the shoal part of the bank and near its northern edge.

Very considerable fluctuations are to be expected in the salinity of the surface along the edge of the continent abreast of the Gulf of Maine, as well as in its temperature (p. 596), as the oceanic water of high salinity approaches the banks or recedes from them.

In the southwestern part of the area, in the offing of Marthas Vineyard, the data for July, 1916, August, 1914, and for autumn (p. 801) make it reasonably certain that surface water as saline as 33 per mille normally drifts in over the outer part of the shelf during July and the first three weeks of August, but seldom (perhaps never) approaches much nearer the shore than is represented on the chart for 1914 (fig. 136).

Farther to the east the isohaline for 33 per mille may be expected to skirt the southern edge of Georges Bank in July, lying a few miles farther in in some summers, farther out in others, and crossing the oceanic triangle between Georges and Browns Bank, but not, in our experience, encroaching at all over the latter. Still farther eastward surface water as saline as 33 per mille overflows the edge of the continent in July or August of some years, as in 1915, when Bjerkan (1919) had still higher readings (34.27 per mille) at the 400-meter contour in the offing of Cape Sable on July 22. In 1914, however, the surface water near by was only 31.22 per mille a week later in the season (station 10233), though the difference in date would suggest a difference in salinity of just the reverse order, evidence of considerable fluctuation in this respect from summer to summer.

It is doubtful whether surface water as salt as 34 per mille ever encroaches on the edge of the continent abreast of the Gulf of Maine; certainly we have no record of such an event at any season, but the surface charts for the winter, spring, and summer (figs. 93, 127, and 136) show that it is to be expected only a few miles out from the 200-meter contour south of Marthas Vineyard and off the western end of Georges Bank by the first half of July in early seasons, but perhaps not until August in late seasons. In some summers, as in 1914, water of this high salinity lies farther out from the edge of the continent to the eastward. In other summers, however, it evidently spreads shoreward over the slope off Shelburne as early in the season as it does farther west—witness the records obtained by the Canadian Fisheries Expedition in 1915, mentioned above (Bjerkan, 1919; *Acadia* station 41).

None of our lines have run far enough out, abreast the gulf, to reach surface water of full oceanic salinity (35 per mille and upwards); nor is it known how far out from the edge of the continent water of 34 per mille withdraws in winter and spring.

ANNUAL VARIATIONS IN SURFACE SALINITY IN SUMMER

Passing reference has been made in the preceding pages to the variations that have been observed in the salinity of the surface from summer to summer. The most interesting fluctuation of this sort that has come to our attention is that surface values averaged much lower in the southwestern part of the region in July, 1916, than in that same month in 1912, 1914, or 1915; the surface of Massachussetts Bay, for instance, was about 1 per mille less saline on July 19 to 20, 1916, than at about the same dates in 1912 or in 1915. Probably the correct explanation is that 1916 was a tardy spring, when the effect of vernal freshening from the land continued evident until later in the season than usual, and when the approach of water of high salinity to the continental shelf was delayed until later in the season. As a result of this retardation of the vernal cycle—associated, no doubt, with the severity of the preceding winter and the lateness of the spring—the salinity of the surface was very nearly uniform on July 24, 1916, right across the whole breadth of the western end of Georges Bank, where a considerable north-south gradation is to be expected at that season in more normal years (fig. 136).

Contrasting with 1916 and with 1914, the summers of 1912 and 1913 may be characterized as "salt" in the western side of the gulf, with surface values averaging about 0.1 to 1 per mille higher at corresponding localities and dates than in 1914—August as well as in July—but with very little difference from summer to summer in the eastern side. The surface values for 1915 paralleled those for 1914 except for the closer approach of oceanic water to the continental shelf off Nova Scotia, mentioned above (p. 771).

No wide annual fluctations in salinity have been recorded for any part of the gulf at a given season, or are such to be expected.

VERTICAL DISTRIBUTION

The salinity of the deep strata of the gulf, like that of the surface, remains more nearly constant during July and August than over any period of equal duration earlier in the summer or in the spring. Two stations in the basin off Cape Cod, four weeks apart in 1914 (stations 10214 and 10254, July 19 and August 22), exemplify this for the western side of the gulf, the values, depth for depth, being nearly alike in spite of the time interval separating them, with the one station slightly the more saline at some levels, the other at other levels.

The graph (fig. 138) illustrates how little variation in salinity has been recorded for the deeper levels in the western side of the basin at different dates in August of different years, individual stations seldom differing by more than 0.2 to 0.4 per mille in either direction from the mean values of 32.6 per mille at 50 meters, 33 per mille at 100 meters, 33.4 per mille at 150 meters, 33.9 per mille at 200 meters, and about 34.1 per mille at 250 meters.

Except in localities where the tide runs strong enough to keep the whole column of water thoroughly mixed from top to bottom, the salinity of the gulf is invariably lower at the surface in summer than on the bottom, as already stated for the spring months. I should emphasize, also, that the increase in salinity with depth is continuous, or at most is interrupted by homogeneous strata; we have never found fresher water underlying salter in the gulf. Thus, the intermediate layer of low temperature, characteristic of certain summers (p. 602), is not reproduced by the salinity; but the vertical distribution varies widely from place to place in the gulf, a convenient division in this respect being (1) into the coastal zone, (2) into the basin, and (3) into the offshore rim.

In the western section of the coastal zone, out to the 100-meter contour, the vertical increase of salinity, with increasing depth, averages much more rapid in the upper stratum than at greater depths, with most of our stations showing a vertical range of 0.6 to 1 per mille between the surface and the 40 to 50 meter level (fig. 139). Eastward from Penobscot Bay we have found a more uniform gradient of salinity from the surface downward, as illustrated by stations near Mount Desert Island (fig. 107).

Throughout the sector between Cape Cod and Mount Desert the difference in salinity between the surface and the 40 to 50 meter level is everywhere considerable in summer (though less than in spring, p. 728)—perhaps nowhere less than 0.3 per

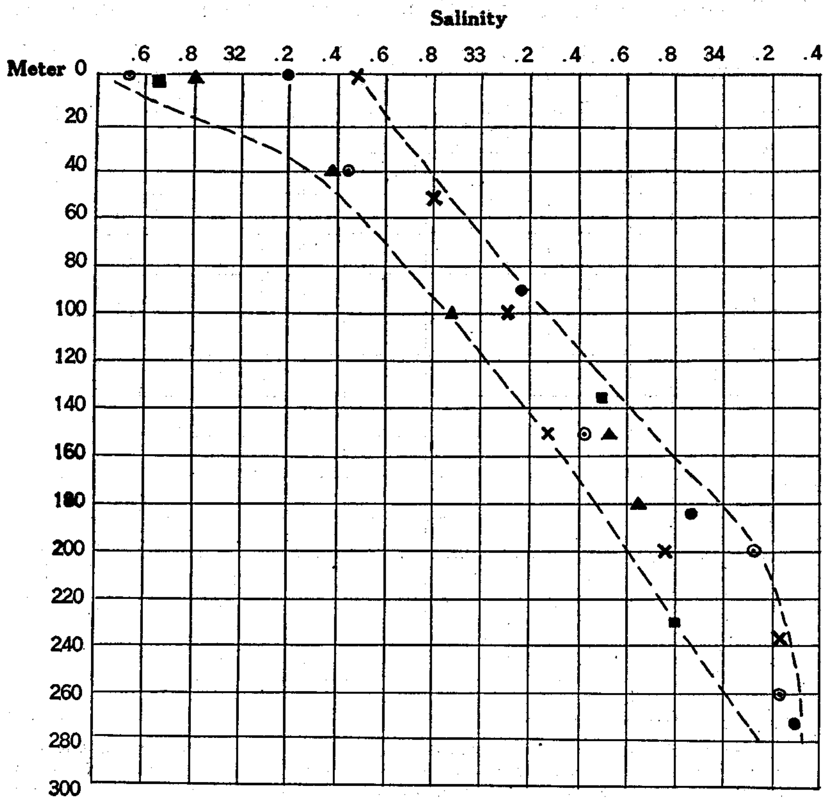

FIG. 138.—Vertical distribution of salinity in the western side of the basin, in the offing of Cape Ann, in July and August of different years. ●, August 9, 1913 (station 10088); ⊙, August 22, 1914 (station 10254); ▲, August 23, 1914 (station 10256); X, August 31, 1915 (station 10307). The broken curve marks the approximate limits to annual variation

mille in July or August, with a maximum vertical range of about 1 per mille in the Massachusetts Bay region within these depth limits.

Passing eastward from Mount Desert toward the Bay of Fundy, the vertical range of salinity is progressively narrower and narrower, corresponding to the more and more active tidal stirring. In the Grand Manan Channel so close an approach to verticle homogeneity is maintained throughout the summer that the maximum vertical range so far recorded for August has been only about 0.08 per mille, as follows:

Station	Date	Depth	Salinity
		Meters	*Per mille*
10035	Aug. 19, 1912	0	32.57
10035	do	82	32.65
Mavor's No. 27	Aug. 27, 1919	0	32.01
Do	do	85	32.09
Mavor's No. 28	do	10	32.14
Do	do	80	32.20

Vachon's (1918) and Mavor's (1923) determinations show that the vertical distribution of salinity within the Bay of Fundy varies regionally in summer, probably

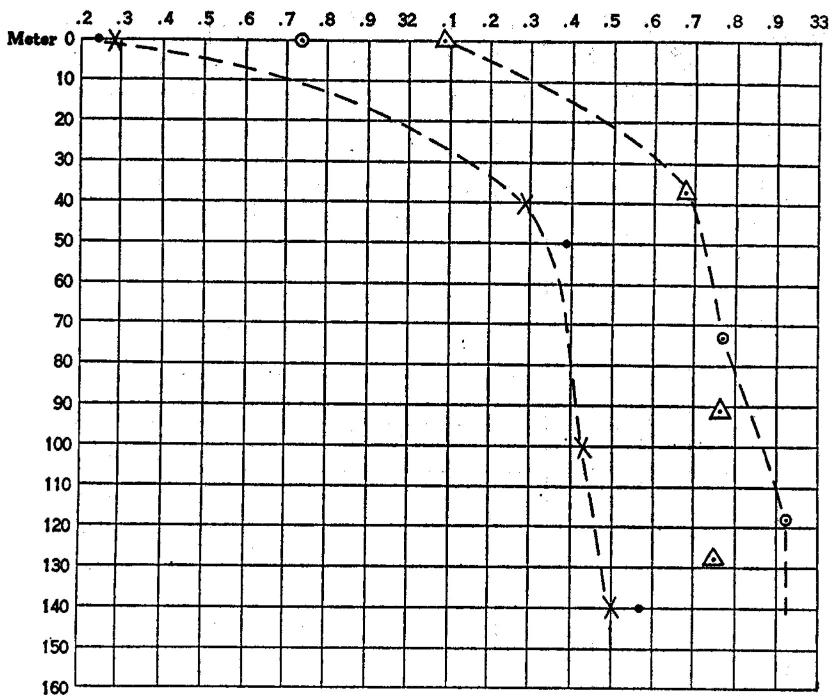

FIG. 139.—Vertical distribution of salinity in the deep bowl off Gloucester in July and August of different years. ⊙, July 10, 1912 (station 10002); △, August 9, 1913 (station 10089); ×, August 22, 1914 (station 10253); ●, August 31, 1915 (startion 10306). The broken curves mark the approximate limits of annual variation

depending on local and temporal variations in the strength of the tidal streams. Where the water is least stirred vertically, and where the surface is least saline because most subject to the freshening effect of the outflow from the St. John River, the salinity of the upper 40 to 50 meters very closely parallels that of the mouth of Massachusetts Bay (fig. 139) and of the western side of the gulf generally, grading from this to the vertical uniformity characteristic of the Grand Manan Channel.

Strong tidal currents are similarly responsible for a close approach to vertical homogeneity over German Bank in August as in spring (p. 748) and early summer (p. 756), the greatest difference between the surface and the bottom at any of our summer stations there being only about 0.3 per mille, as follows:

Salinity on German Bank, August to September

Station	Date	Depth	Salinity	Vertical range
		Meters	*Per mille*	*Per mille*
10029	Aug. 14, 1912	0	32.70	0.22
		64	32.92	
10065	Aug. 12, 1913	0	32.75	.19
		55	32.94	
10244	Aug. 12, 1914	0	32.84	.06
		55	32.90	
10311	Sept. 2, 1915	0	32.23	.33
		65	32.56	

In the deeper parts of the gulf the vertical distribution of salinity at depths greater than 50 to 70 meters depends less on the tide (very active tidal stirring is

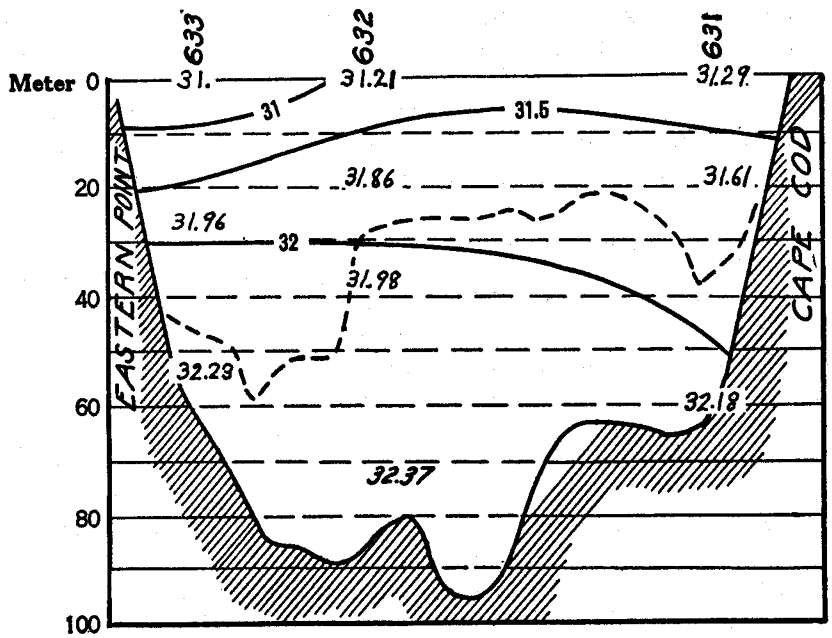

FIG. 140.—Salinity profile crossing the mouth of Massachusetts Bay, Gloucester to Cape Cod, just west of Stellwagen Bank, August 22, 1922. The broken curve is the contour of the bank

for the most part confined to the shoaler parts of the gulf) than on the configuration of the bottom, as affecting the free circulation of the water of high salinity that drifts into the basin via the trough of the Eastern Channel. One extreme is illustrated by the deep bowl or sink off Gloucester, where a depth of 181 meters is inclosed by a rim rising to within about 75 meters of the surface at its deepest point. Here, on each of our summer visits (figs. 104 and 139), we have found a very rapid increase in salinity with depth down to the 40 to 50-meter level, succeeded by a much more gradual increase from that depth down to the bottom. More concretely, the maximum vertical range between 40 meters and bottom has been only about 0.2 per mille here at any summer station, contrasting with a range of 0.6 to 1 per mille of salinity between the surface and the 40-meter level. Evidently the submarine rim of this bowl is so effective a barrier that the water inclosed by it is but little influenced by the slope water in the bottom of the basin near by, but continues through the summer at about the same salinity that characterizes the overlying stratum in early spring.

Stellwagen Ledge, at the mouth of Massachusetts Bay, also isolates the deeper water behind it to some extent, as shown by the correspondence between the contour of the bank and the isohaline for 32 per mille on the profile for August, 1922, and by the homogeneity of the deeper water contrasted with the wide vertical range in the shoaler strata (fig. 140).

Although the deep sink to the west of Jeffreys Ledge is open to the north, where its rim has a depth of about 134 meters, the narrowness of the opening on this side combines with the north-south direction of the axis of the ledge and with the shoalness (48 to 64 meters) and comparative steepness of the latter to hinder the drift of bottom water westward from the open basin of the gulf. Two stations in the trough for August 15, 1913, are especially interesting in this connection because the southern (inner) one of the pair was nearly homogeneous in salinity at depths greater than 50 to 60 meters, though the outer one showed a rapid increase in salinity from the surface downward to a depth of about 90 meters. Evidently comparatively little interchange was then taking place along the trough in the deep strata.

Sometimes, however, bottom water of high salinity does drift inward, around the northern end of Jeffreys Ledge, into this trough in much greater volume; as in August, 1914, for instance, when a difference of 0.4 per mille in salinity was recorded between the 40 to 50 meter level and the bottom (station 10252).

The relationship between the deep strata of the Bay of Fundy and the basin outside, from which it is separated by a low submarine ridge, is of this same order in summer, with the vertical rise in salinity much more rapid above than below the 50 to 70-meter level in the bay (Mavor, 1923), whereas the increase in salinity with depth in the basin off its mouth is most rapid near the bottom (fig. 114).[97] A difference in vertical distribution of this sort shows as clearly as does the much higher salinity (34 per mille) of the bottom of the basin that only a small amount of water from the deeps of the latter was then entering the bay.

The distribution of salinity has been more uniform, regionally, at most of our summer stations in the inner parts of the basin of the gulf down to a depth of about 200 meters. In the western branch, where the superficial stratum is influenced by the dispersal of land water, slight geographic differences in the locations of the stations and secular changes in the surface currents produce corresponding differences in the curves for salinity, depending on the precise state of the surface water. At greater depths the vertical salting may either continue at an undiminished rate right down to the bottom, as was the case on August 31, 1915 (station 10307, fig. 138), or the deepest stratum (more saline than 34 per mille) may form a homogeneous blanket on the bottom, 50 to 60 meters thick, as we found it on August 22, 1914 (station 10254, fig. 112).

A much thicker and considerably more saline (35 per mille) layer had blanketed the bottom of the southeastern part of the basin a month earlier that summer (station 10225, fig. 131), but with the salinity increasing rapidly with depth in the

[97] Stations 10097 (August, 1913), 10246 (August, 1914), and 10304 (August 6 and 7, 1915).

shoaler strata of water, reproducing the vertical distribution found there (though somewhat more saline in actual values) in March and April of 1920 (stations 20064 and 20112), hence this type is probably characteristic of that part of the gulf.

The state of the deep water in the two channels—eastern and northern—that interrupt the offshore rim of the gulf is worth stating, these being the possible sources for deep undercurrents flowing inward. In July, 1914 (our only late summer stations for this locality), the vertical distribution of salinity was almost precisely the same in the Eastern Channel as in the southeastern part of the gulf, into which the latter debouches, as were the actual values at different depths, with so little difference between the values in the channel for the months of March, April, June, and July in different years (fig. 141) as to prove the salinity of its deeper strata virtually

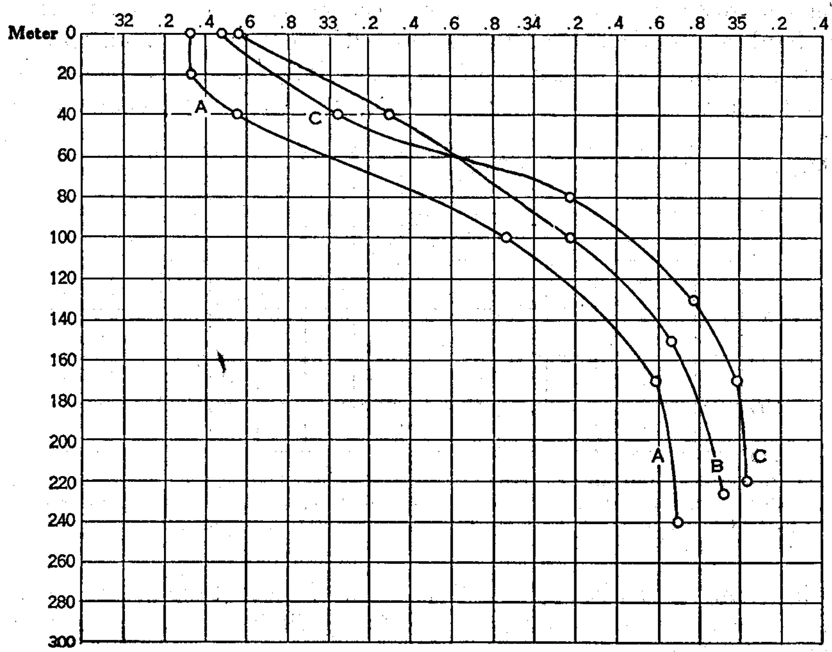

FIG. 141.—Vertical distribution of salinity in the Eastern Channel. A, April 16, 1920 (station 20107); B, June 25, 1915 (station 10297); C, July 24, 1914 (station 10227)

unchanging there through spring and summer. The Northern Channel, on the other side of Browns Bank, at the same date (station 10229, July 25, 1914), was about 1.5 per mille less saline than the Eastern Channel on bottom (100 meters), though only about 0.5 per mille less so at the surface.[98] Consequently, any drift over the bottom via this route would have brought water much less saline to the gulf, as is also the case in spring (fig. 99).

Our late summer stations yielded almost precisely the same salinity on Browns Bank (station 10228) as in the Eastern Channel to the west of it and in the neighboring part of the basin of the gulf, correspondingly salter than the Northern Channel to the north (cf. fig. 141 with fig. 142), evidence of an overflow from the Eastern

[98] 32.47 per mille at the surface at station 10227; 32.01 per mille at station 10229.

Channel as the normal seasonal sequence to the late June state of 1915, a type of circulation also suggested by a corresponding rise in bottom temperature on Browns Bank (p. 619).

Much lower salinities, however, on the neighboring parts of Georges Bank at this same date[99] are equally clear evidence that no drift had taken place westward from the channel; nor have we ever found any indication of an overflow in that direction.

It is probable that offshore water encroaches over the outer edge of Georges Bank to some extent during most summers, at deeper levels as well as at the surface (p. 771), an event made evident in 1914 by the very high salinity of the bottom water (34.9 per mille) on its southwest part on July 20 (fig.142, station 10216). The effect of this highly saline water, however, was so closely confined to the southern side of the bank at the time, that a station on its northern part, only 42 miles away (station 10215) showed no evidence of it, the salinity not only being much lower (32.09 to 32.9 per mille) but the whole column much more nearly homogeneous

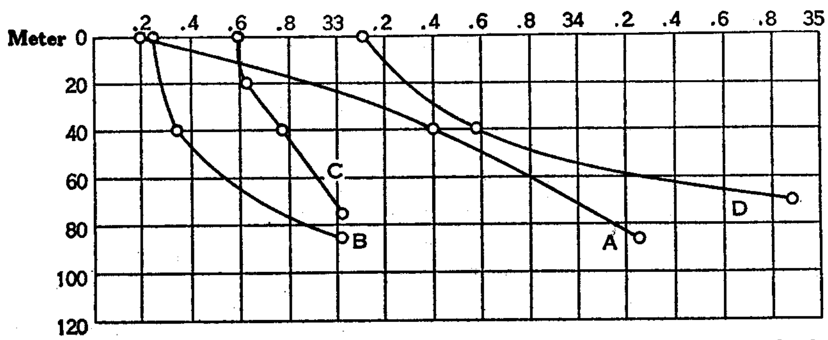

FIG. 142.—Vertical distribution of salinity on the offshore banks in July, 1914. A, Browns Bank, July 24 (station 10228); B, northeast part of Georges Bank, July 24 (station 10226); C, eastern part of Georges Bank, July 23 (station 10223); and D, southwestern part of Georges Bank, July 20 (station 10216)

surface to bottom. Nor did any overflow from offshore take place farther east on Georges Bank in 1914 up to the last week of July (if it ever does), although water of 34 to 35 per mille then washed the bottom below the 100-meter contour all along the outer edge of the bank (stations 10217, 10219, 10221, and 10222).

In summers when the seasonal cycle is more backward (1914 seems to have been rather a forward year in this respect) oceanic water may not encroach on the bottom on any part of Georges Bank before August and perhaps not then. In 1916, for example, two stations on the western and southwestern parts of the bank (10347 and 10348) gave no evidence of any such event on July 23, the salinity being nearly uniform vertically at both, its value (32.4 to 32.6 per mille) no higher than the mean for the whole column on the northern parts of the bank at about that same date in 1914.

Wide regional variations in salinity are to be expected over the broken bottom of Nantucket Shoals, depending on the strength and on the mixing effects of the tidal

[99] Station 10223 and 10224, 32.6 to 33.03 per mille in 55 to 75 meters; fig. 142.

currents. Unfortunately, no stations have been occupied there at the more tide-swept localities, where salinity, like temperature (p. 605), is probably kept nearly homogeneous vertically throughout the summer. A difference of 0.41 per mille of salinity between the surface (31.73 per mille) and the bottom (32.14 per mille, depth 30 meters) was recorded on the southwestern edge of the shoals on July 25, 1916 (station 10355), with about this same vertical range at a station close to Nantucket Lightship on July 9, 1913 (station 10060; salinity 32.63 per mille at the surface, 32.04 per mille at 46 meters). A vertical distribution of this same sort has prevailed in shallow water off Marthas Vineyard in July and August (stations 10356 and 10357, July 26, 1916; 10258 and 10263, August 25 and 27, 1914), the water as usual saltest on bottom.

Farther out on this sector of the shelf, where the vertical distribution varies at any given locality and date according to what overflow of oceanic water has recently taken place and at what level, the mid depths may be less saline than either the

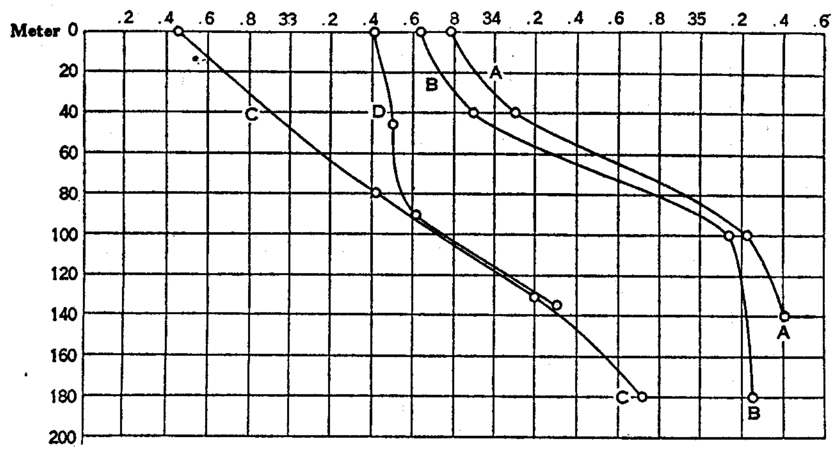

FIG. 143.—Vertical distribution of salinity on the outer part of the continental shelf off Nantucket and Marthas Vineyard. A, August, 1914 (station 10260); B, August 26, 1914 (station 10262); C, July 24, 1916 (station 10351); D, July 10, 1913 (station 10061)

surface or bottom, as was the case at station 10259 on August 25, 1914. However, there is every reason to suppose that such a state is exceptional and probably transitory, and that the vertical distribution is usually of the same type there (freshest at the surface, saltest on the bottom; fig. 143) as it is nearer the land and within the Gulf of Maine.

Our summer stations outside the edge of the continent, whether abreast of the Gulf of Maine or a few miles to either side of the meridians bounding the latter, have all shown a very rapid increase in salinity with increasing depth in the superficial stratum (fig. 144), though with wide differences in the actual values from station to station. In part these differences depend on whether the oceanic water lies far out from or close in to the banks at the time, but also on the precise location of the stations in question, because the transition from banks to ocean is so abrupt along this zone that a difference of half a dozen miles in geographic position may be accompanied by a very wide difference in the salinity of the surface water as well as in its temperature (p. 605).

As stated, 1916 was so tardy a summer that the very close agreement between the curves off Georges Bank for that July (station 10352) and off Cape Sable in July, 1914 (station 10233, fig. 144), is deceptive; equal salinities are usually attained about a month later in the season off the eastern portal to the gulf than off the western.

When the highly saline water of the ocean basin moves closest in toward the edge of the continent, whether to the east or to the west of the Eastern Channel

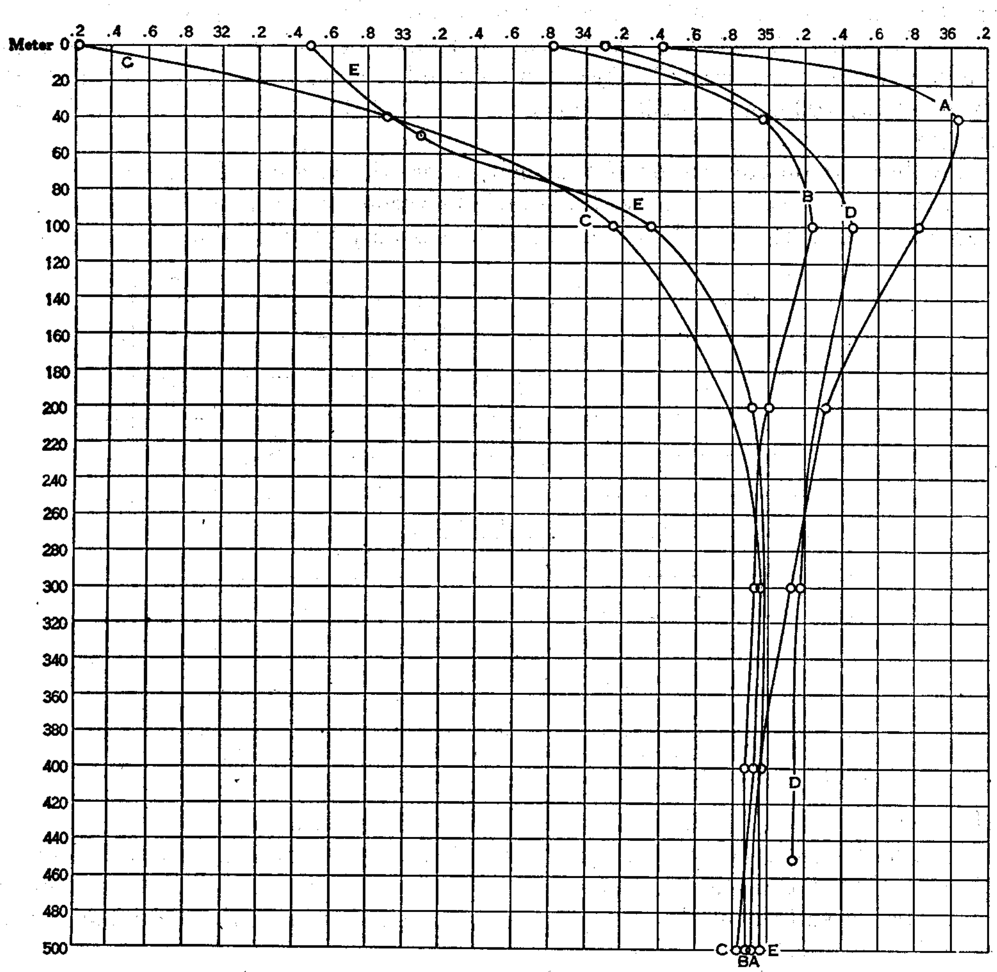

FIG. 144.—Vertical distribution of salinity along the continenta lslope abreast of the Gulf of Maine in summer. A, southwest slope of Georges Bank, July 21, 1914 (station 10218); B, southeast slope of Georges Bank, July 22, 1914 (station 10220); C, abreast of Shelburne, Novia Scotia, July 28, 1914 (station 10233); D, south of Marthas Vineyard, August 26, 1914 (station 10261); E, southwest slope of Georges Bank, July 24, 1916 (station 10352)

(p. 771), a very characteristic vertical distribution results, with the values highest at a depth of 40 to 100 meters. Station 10218, off the southwest slope of Georges Bank (our most oceanic station in temperature as well as in salinity), showed such a distribution on July 21, 1914 (fig. 144), with a maximum salinity approximating full oceanic value (36.04 per mille) at 40 meters, though with the surface water much less saline (34.42 per mille). Stations a few miles farther east along the slope, the next day (10220), and at the same relative position off Marthas Vineyard on the 26th of that August (10261), yielded salinity sections similar in type (fig. 144), though with actual values considerably lower in the upper 150 meters. The bottom water at all these stations has been close to 35 per mille at depths greater than 300 meters.

None of our stations have been located far enough out from the edge of the continent to show the true tropical-oceanic distribution of salinity—namely, saltest at or very close to the surface and decreasing with increasing depth down to 600 to 1,000 meters. Curves of this sort result, for example, from the observations taken by the United States Coast Survey steamer *Bache* on her profile from Bermuda to the Bahamas in January, 1914 (Bigelow, 1917a, figs. 8 and 9), and by the *Dana* near Bermuda in May, 1922 (Nielsen, 1925, fig. 5); but when the so-called "inner edge of the Gulf stream" approaches the edge of Georges Bank, as in July, 1914, doubtless one need run off only a few miles into the oceanic basin to find the salinity so distributed there.

GENERAL DISTRIBUTION OF SALINITY BELOW THE SURFACE

The spacial relationships of the differences in salinity just outlined and the general state of the gulf in summer are made more graphic by the usual projections—horizontal and profile.

The salting of the eastern side of the gulf, which takes place from June to August (p. 765), contrasted with the freshening of the western side of the basin as land water is dispersed seaward (p. 763), produces a decided alteration in the distribution of salinity from late spring through the summer at moderate depths as well as at the surface (p. 763). In 1915 these changes resulted in an increase in the salinity of the 40-meter level from about 32.5 per mille to about 32.8 to 33.5 per mille in the northeastern part of the basin during the interval between the last week of June (fig. 133) and the end of August, contrasting with a decrease in its western side from about 32.9 per mille to about 32.6 per mille, though very little seasonal alteration took place meantime in the coastal zone near Mount Desert, on the one hand (about 32.3 per mille), or near Cape Sable on the other (about 31.9 per mille).

The most interesting feature of the 40-meter chart for July and August, 1914 (fig. 145), which may be taken as typical of the season (there being no reason to suppose that this was either an abnormally fresh or an abnormally salt year), is the regular gradation from low values in the western side of the gulf to a tongue of high salinity (33+per mille) in the eastern side of the basin, again giving place to a narrow zone of much fresher water along western Nova Scotia, with still lower values (31.8 per mille) near Cape Sable and eastward along the outer coast of Nova Scotia (Bigelow, 1917, fig. 33).

A much wider extent of 33 per mille water in that August than is shown on the May and June charts for 1915 (figs. 125 and 133) no doubt reflects some seasonal drift inward from the Eastern Channel after the slackening of the Nova Scotian current, with the isohaline for 32.9 per mille revealing a tendency for the saltest band to circle westward along the coastal slope of Maine, bringing salinities as high as 32.9 to 33 per mille as far as the offing of Penobscot Bay. A tongue of this same sort and of about the same salinity (33 to 33.2 per mille) also characterized the 40-meter level in August, 1913 (fig. 146); and while the most saline water (33 per mille) did not form so definite a tongue in 1912 (Bigelow, 1914), a regional

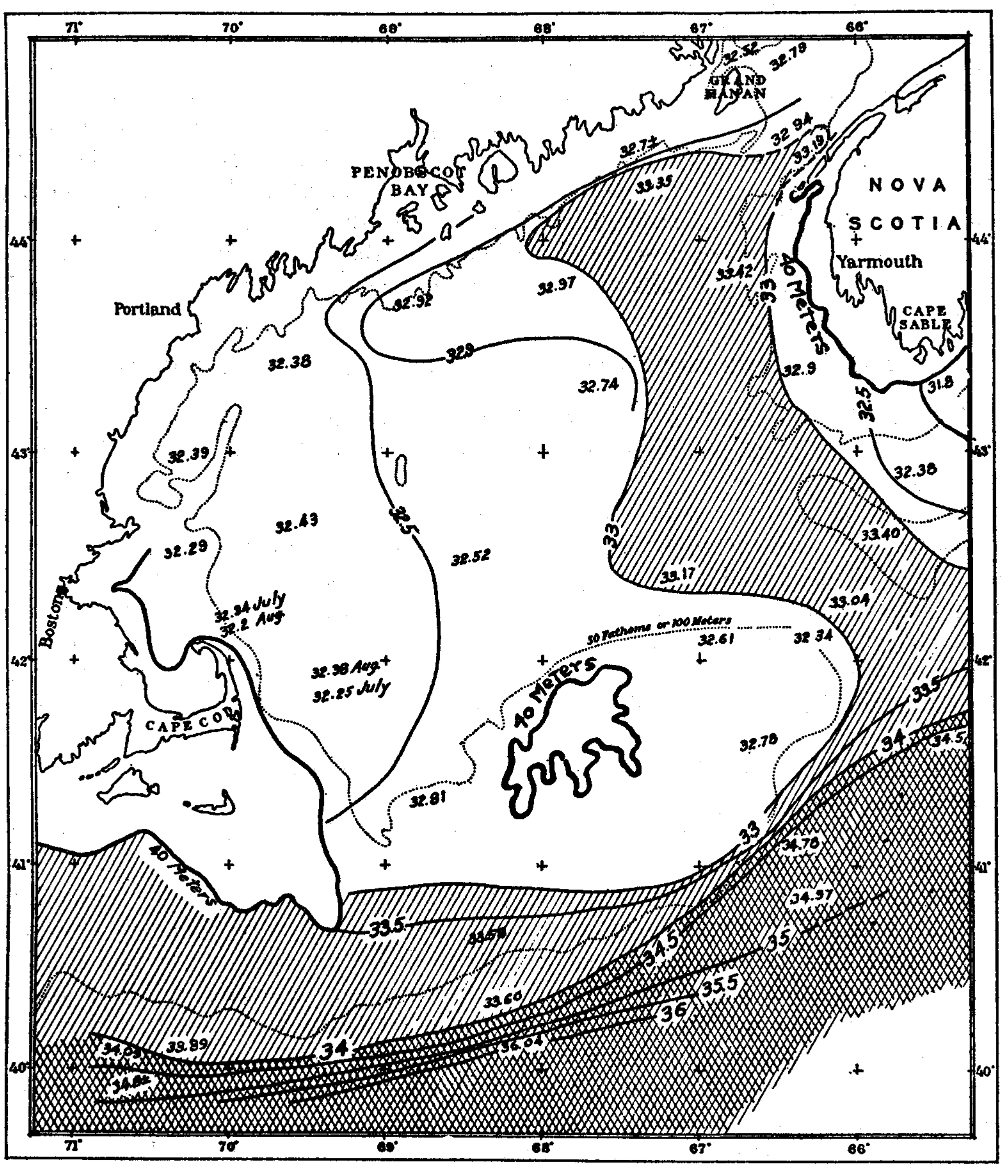

FIG. 145.—Salinity at a depth of 40 meters, July 19 to August 24, 1914

distribution of the type just described has reappeared frequently enough on the charts for various levels, months, and years to establish it as normal for the gulf.

Densities determined by Craigie (1916a) for August 27 to 29, 1914, when reduced to terms of salinity also show this saline water (33 per mille) curving into the southern side of the Bay of Fundy along its Nova Scotian side, with a regular decrease in salinity from south to north across the bay to about 32.5 per mille near Campobello Island. Recurrence of a regional distribution of this same sort in the bay in August, 1916 (Vachon, 1918) and 1919 (Mavor, 1923), proves it characteristic of the 40-meter level there at the end of the summer, though the actual values were somewhat lower in those two years than in 1914.

Corresponding to the contraction of the area of the gulf with increasing depth, this salt tongue gives place to a gradation from low salinity to high across the basin from west to east at deeper levels, as illustrated by the 100-meter chart for July and August, 1914 (fig. 147), on which the successive isohalines (33 and 33.5 per mille) outline the same eddying movement of the saltest water westward, past the offing

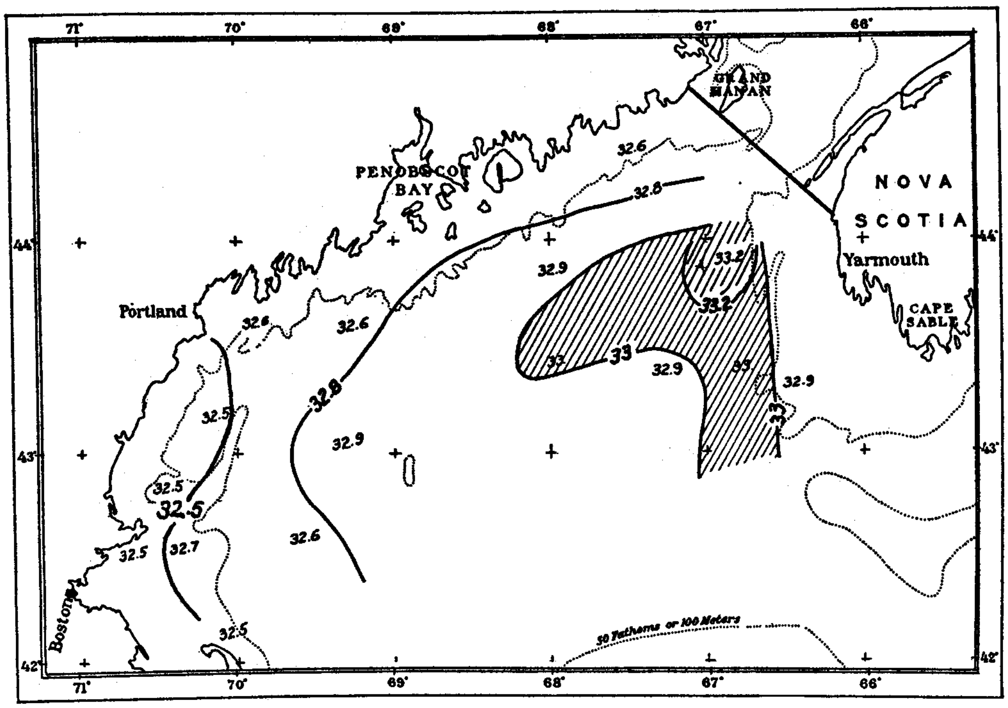

FIG. 146.—Salinity at a depth of 40 meters, August 5 to 20, 1913

of Penobscot Bay, as at 40 meters (p. 781). Some west-east gradation of this sort has been recorded on each of our August cruises at the 100-meter level; but the actual difference in salinity between the highest values in the eastern side of the gulf and the lowest in the western side was much wider in 1914 than in 1913 when the regional range was only from about 33.1 to about 33.5 per mille at 100 meters, with the whole west-central part of the basin close to uniform, regionally, at 33.1 to 33.3 per mille (fig. 148).

The gradual absorption of the indraft from the Eastern Channel into the general complex of the gulf is more clearly illustrated on the 100-meter chart for 1914 (fig. 147) than at shoaler lines by the successive decrease in salinity, passing inward from the channel (34.4 per mille), to about 33.6 per mille in the northeastern corner of the gulf.

At still deeper levels the distribution of salinity becomes increasingly governed by the contour of the bottom as this more and more confines the inflowing slope

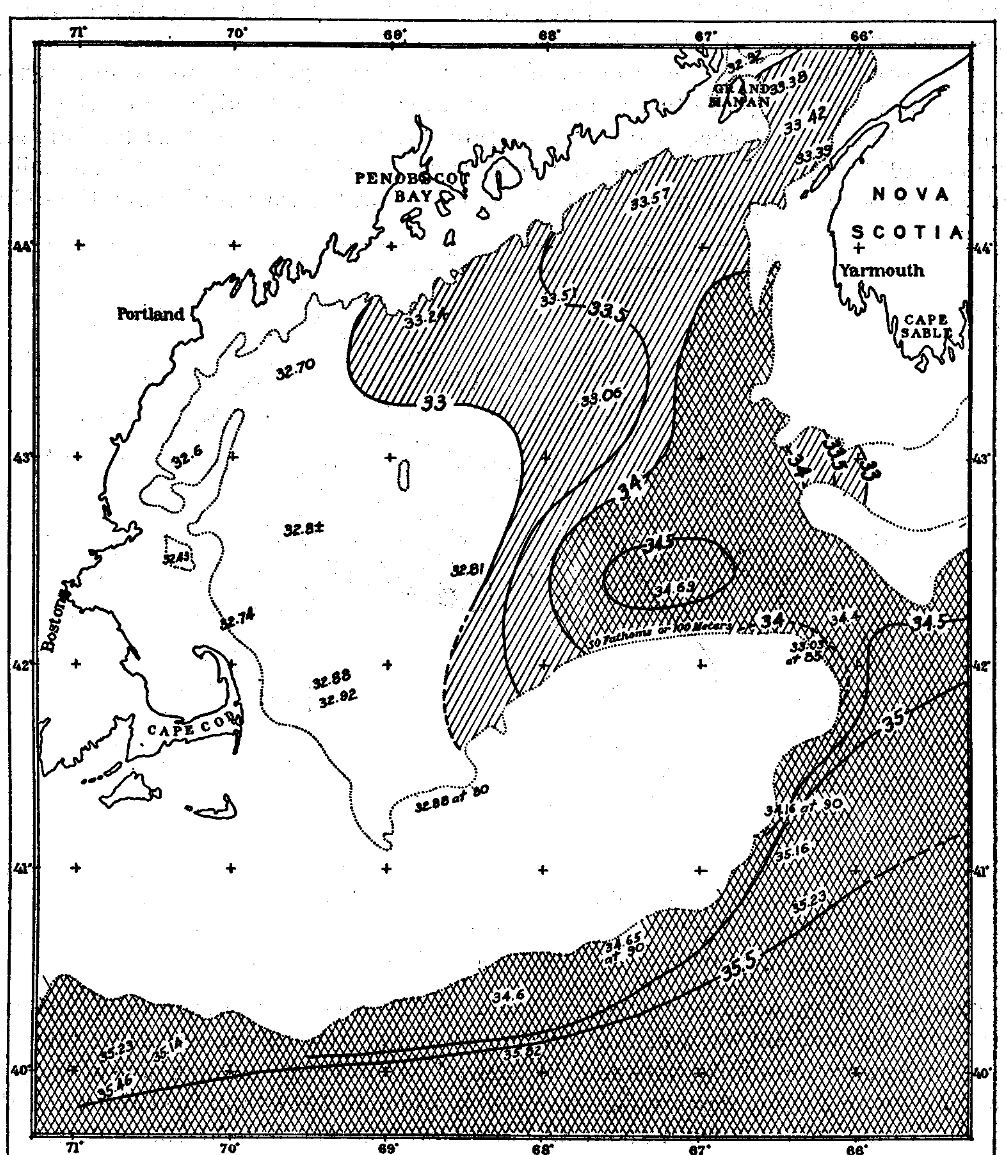

FIG. 147.—Salinity at a depth of 100 meters, July 19 to August 26, 1914. Bay of Fundy from Craigie

water. Thus the latter (34 per mille) was not only directed more into the eastern arm of the Y-shaped trough at 175 meters than into the western in 1914 (fig. 149), but hugged the eastern slope of the former, making it the site of an anticlockwise circulation. This seems also to have been the case in 1912,[1] with absolute values varying from 34.3 per mille in the extreme northeast, off Machias, Me. (10036), to 33.5 per mille in the depression between Platts Bank and Cashes Ledge (station 10024). In 1915 the summer was likewise of this same type in the deeps of the gulf, with 34 to 34.1 per mille in the eastern side and 33.5 per mille in the western at the 175-meter level; but in other summers the salinity of the deep strata is more nearly uniform over the basin, as in 1913, when the values at 175 meters were 33.8 to 33.9 per mille in the western and eastern sides alike.[2]

At depths greater than 200 meters the indraft through the Eastern Channel does not have as free access to the two branches of the basin as at higher levels Consequently, their bottom waters have proved considerably less saline (34.5 per

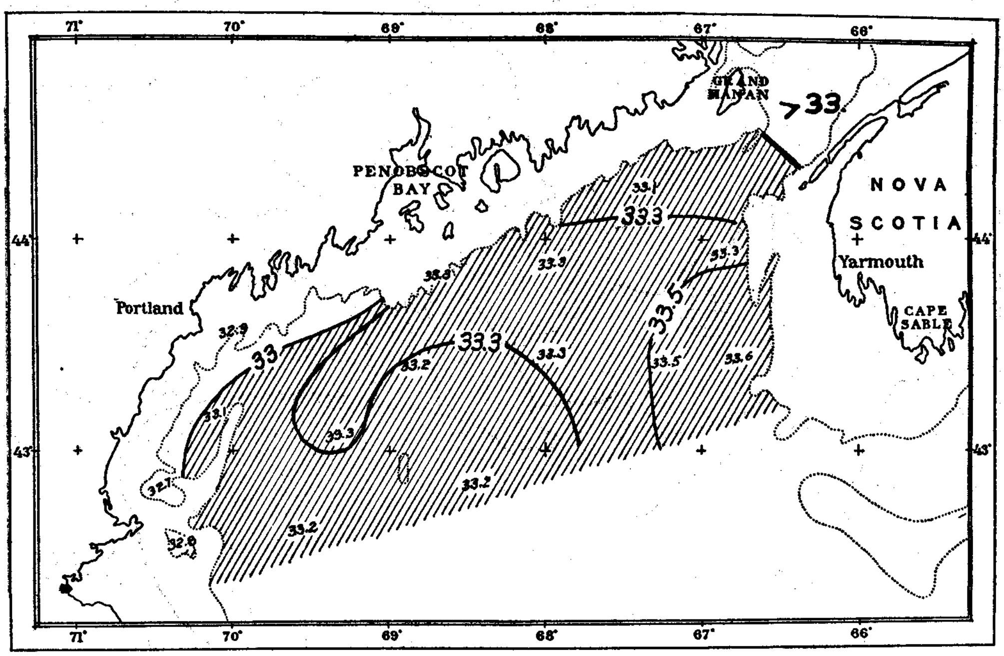

FIG. 148.—Salinity at a depth of 100 meters, August 5 to 20, 1913

mille) than their union to the southeast, or than the Eastern Channel (35 per mille). The bottoms of the deep bowl-like depressions in the offing of Cape Ann, in the one side of the gulf, and off the mouth of the Bay of Fundy in the other, thus bear much the same relationship to the still deeper bowl into which the Eastern Channel opens as the sink off Gloucester and the other isolated sinks in the inner parts of the gulf bear to its basin in general.

At the 200-meter level (fig. 150) all the July and August determinations for the western bowl (stations 10007, 10088, 10254, and 10307) have ranged between 33.7 per mille and 34.11 per mille, showing that very little annual variation is to be expected there or regionally within its narrow confines. In the eastern bowl the

[1] Only 5 stations were located in water as deep as 175 meters in 1912, and at only 3 of these can the 175-meter value be stated within ±0.1 per mille.

[2] No observations were taken in the southeastern part of the area in August of 1912, 1913, or 1915.

salinity has averaged higher, most of the determinations falling between 34 per mille and about 34.5 per mille, with the highest readings localized along the eastern and northern slope and the lowest (33.4 to 33.6 per mille) in its southwestern side (stations 10249, Aug. 13, 1914, and 10309, Sept. 1, 1915).

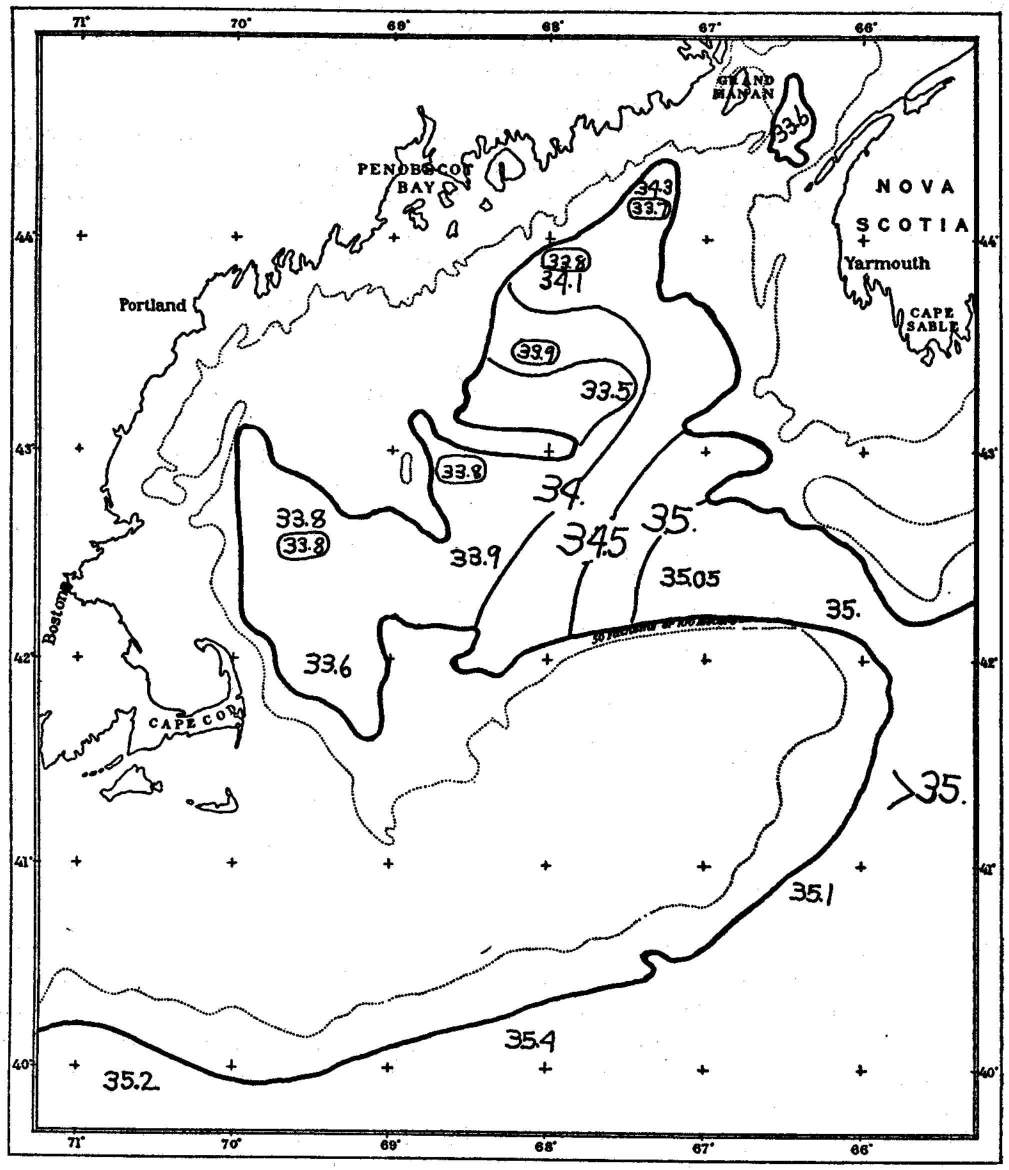

FIG. 149.—Salinity at a depth of 175 meters for August, 1913 (encircled figures), and for July 19 to August 26, 1914 (plain figures). Data for the Bay of Fuudy from Craigie (1916a)

The midsummer charts, compared with the state of the gulf in June (p. 762), suggest an interesting seasonal progression, with the slope water of high salinity (34 per mille) spreading inward from the channel over the bottom, to occupy all the southeastern part of the gulf and northward to the northern slope. It is possible that in some years the inflow may continue actively until late in August; but the data for 1913, 1914, and 1915 make it more likely that the indraft usually slackens by the first of July, if not earlier, when a progressive tendency toward the regional

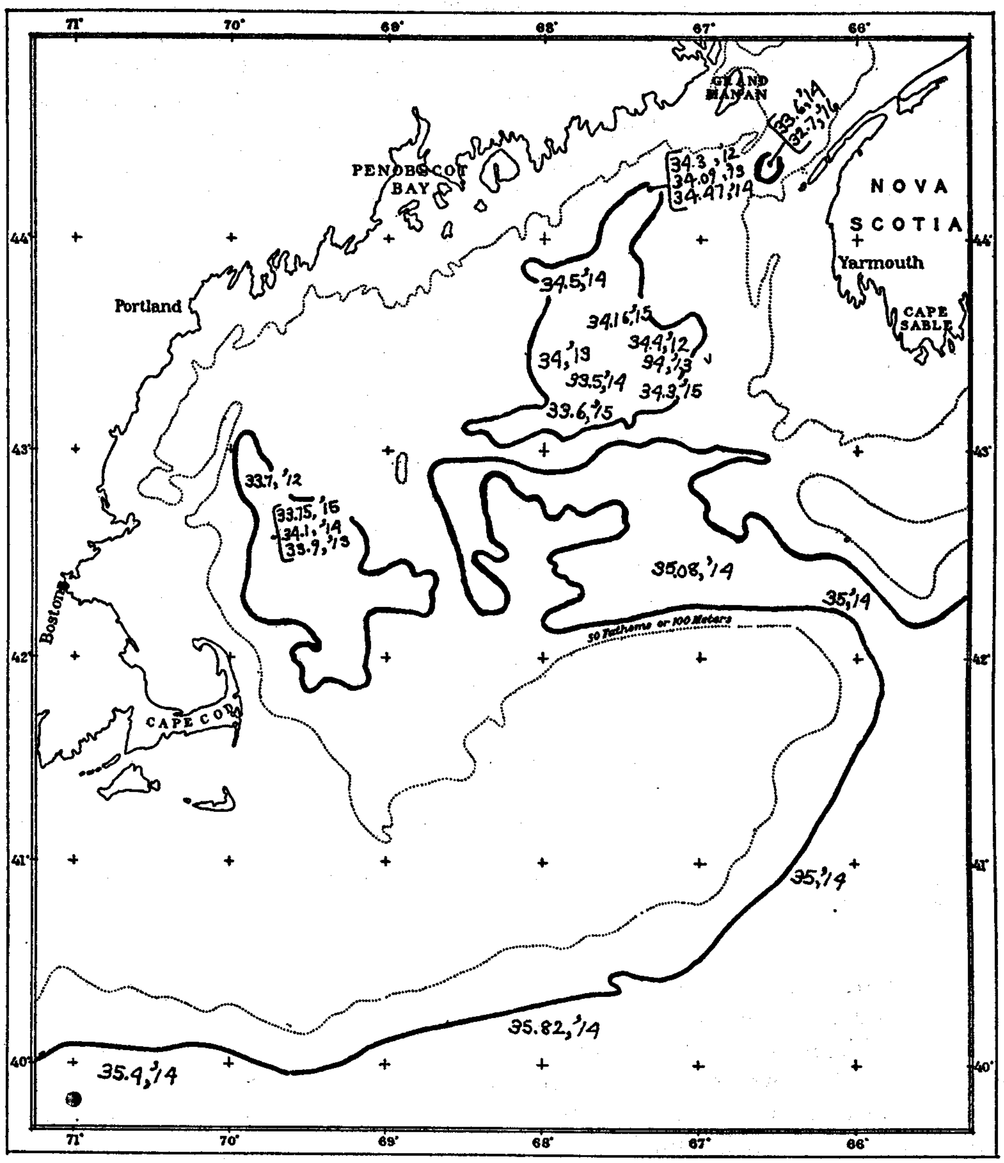

FIG. 150.—Salinity at a depth of 200 meters, July and August, 1912 to 1915

equalization of salinity naturally ensues by various local circulatory movements of the water. It is also possible that slope water enters in much greater volume in some years than in others.

It seems, however, that these changes involve the Bay of Fundy to only a small degree at 100 meters or deeper, for in 1917 the salinity at that level changed from 32.4 per mille on July 4 to about 33 per mille on September 3 at a station off Grand Manan (Mavor, 1923, p. 375). Values differing little from this are evidently to be expected in the bay at this depth at the end of most summers, witness Craigie's (1916a) records of 33.3 to 32.4 per mille in 1914[3] and Mavor's (1923) of 32.6 to 33 per mille in 1919. However, sufficient water of high salinity flows into the bottom of the bay in late summer to maintain a more or less constant (though slight) differential between lower values along its northern side and higher values in its trough, with the water along its Nova Scotian slope intermediate in salinity at depths greater than 100 meters instead of most saline, as it is at the 40-meter level (p. 783).

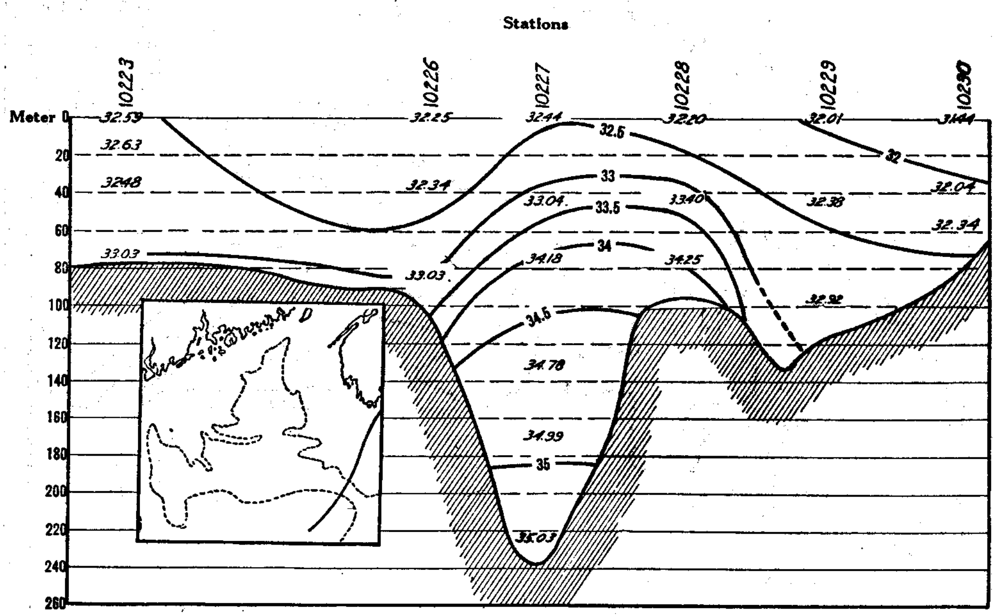

FIG. 151.—Salinity profile running from the eastern part of Georges Bank (stations 10223 and 10226) across the Eastern Channel (station 10227), Browns Bank (station 10228), and the Northern Channel (station 10229), to the offing of Cape Sable (station 10230), for July 23 to 25, 1914

PROFILES

The relationship that the slope water of high salinity in the Eastern Channel bears to the shallows on either hand, and especially to the overflow over Browns Bank, is most graphically illustrated on the July profile (fig. 151), as is the fact that the eastern edge of Browns was its extreme boundary in that direction (and always has been in our experience), where it gives place by abrupt transition to much less saline water in the Northern Channel, and so in toward the land near Cape Sable. The profile also corroborates the evidence of the charts to the effect that this water of high salinity was not overflowing at all on Georges Bank at the time. In fact, it is doubtful if it does so at any season, for we have found no evidence of such an event, either in spring or in summer.

Calculated from Craigie's hydrometer readings.

The course of the isohaline of 32.5 per mille over Georges Bank in this profile is also worth comment in connection with the northeastern to southwestern tongue of low salinity and low temperature recorded there at the surface (p. 770) as evidence of a counter movement out of the gulf, eddying clockwise around the eastern end of

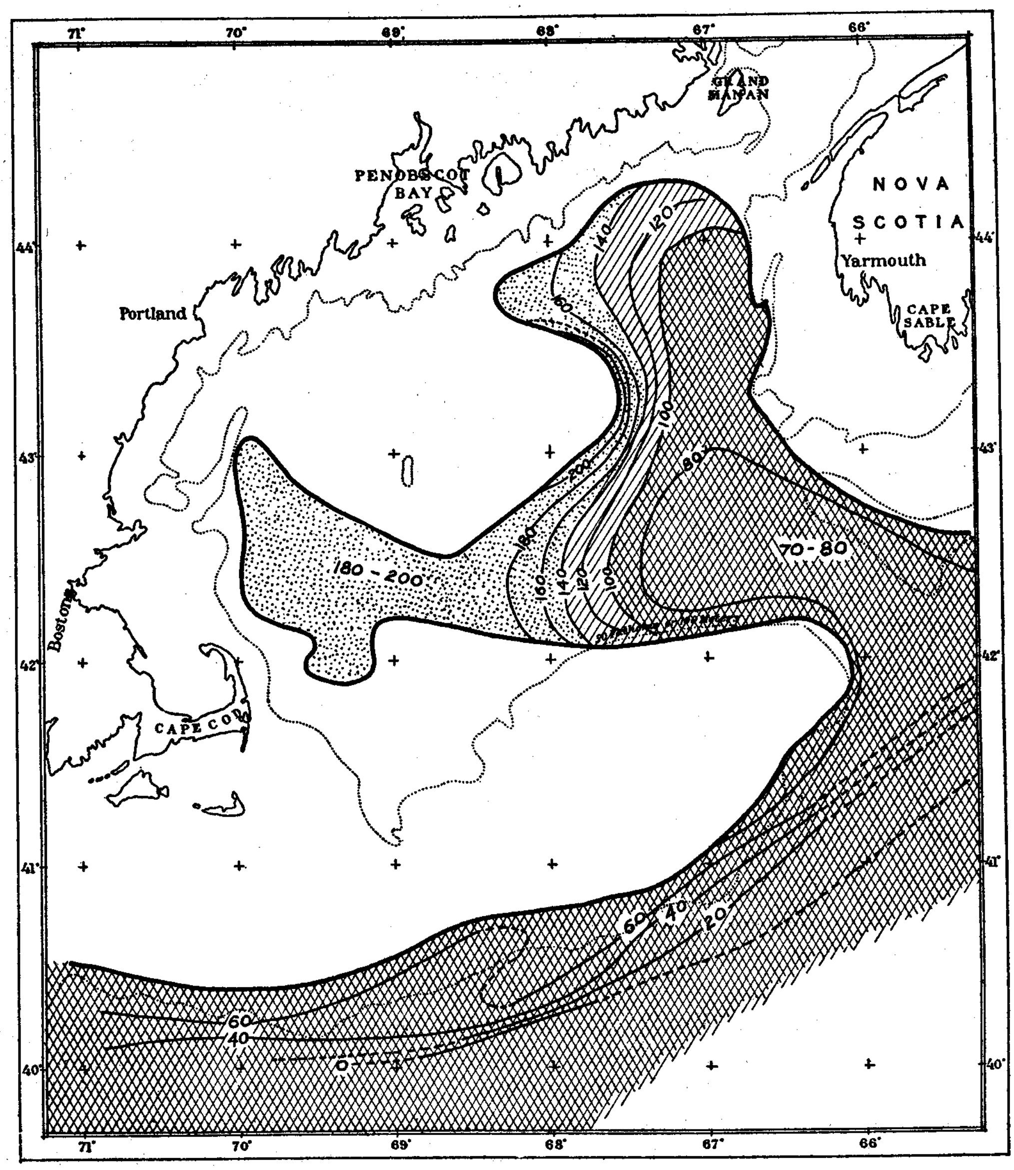

FIG. 152.—Depth below the surface of the isohalobath for 34 per mille, July to August, 1914

the bank (fig. 207). The confinement of the slope water between the banks is also illustrated by a summer chart of the 34 per mille water (fig. 152), as is its extent at that season compared with the spring (fig. 118).

The constant tendency of the slope water to bank up against the eastern (Nova Scotian) slope of the gulf as it drifts inward over the bottom has been mentioned repeatedly in the preceding pages. The consequent concentration of the highest salinities (34 per mille) in the eastern side of the basin, reappearing from month to month on the charts for the deeper levels, is illustrated perhaps more clearly on a profile running from the center of the gulf toward Cape Sable for August, 1914 (fig. 153), than on any of the others, though corresponding profiles for August, 1913 (Bigelow, 1915, fig. 48), and for August-September, 1915 (fig. 154), show something of the sort. On August 12 and 13, 1913, for example, the isohaline for 33 per mille in profile revealed a very decided banking up in the mid-strata on the Nova Scotian slope off

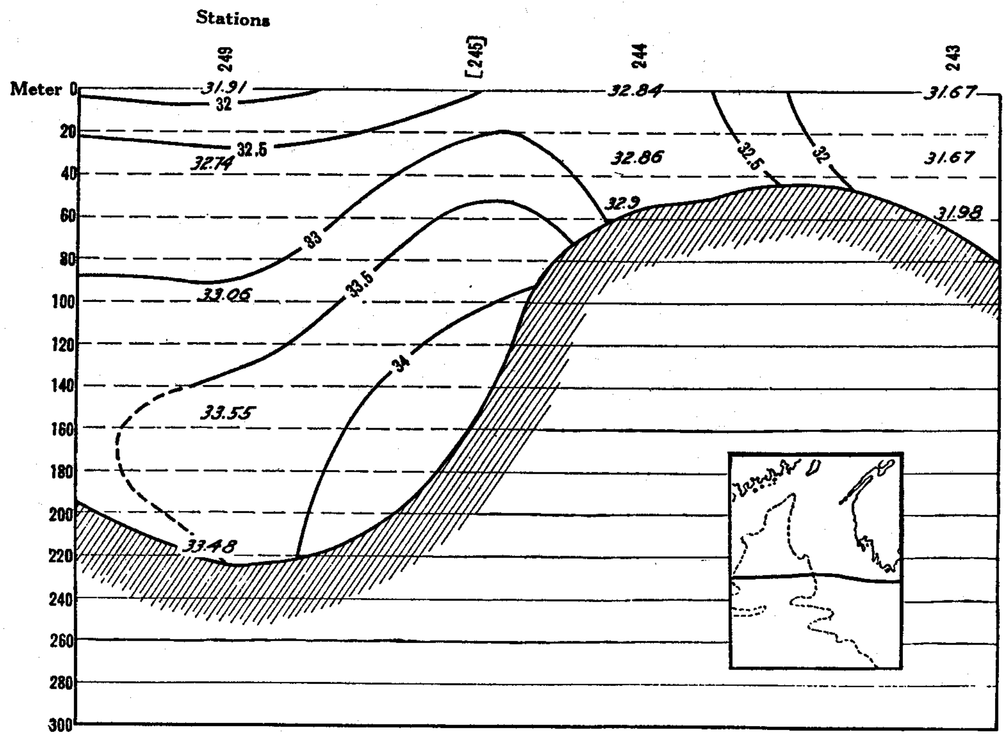

FIG. 153.—Salinity profile running eastward from the offing of Cape Sable (station 10243) toward the center of the Gulf of Maine (station 10249), for August 11 to 13, 1914

the mouth of the Bay of Fundy (Bigelow, 1915, fig. 53), although not of the deepest and most saline water. In 1914 this banking up involved the whole column of water right up to the surface at the time of our cruise. In this region of such active tidal circulation, however, sporadic vertical movements of this sort are to be expected; a profile run a few days earlier or a few days later might have agreed more closely in this respect with the profiles for 1913 and 1915.

In 1913, 34 per mille water occupied the whole breadth of the eastern arm of the basin. In 1913 and 1914, however, slightly lower salinities prevailed in its western side, a difference reflecting a corresponding difference in the circulation of water over the bottom for the preceding weeks.

The eastern ends of the summer profiles along this general line confirm the evidence of the charts to the effect that the flow of Nova Scotian water past Cape Sable nearly or quite ceases before July, by the extremely abrupt transition in salinity between the stations just to the west of the cape (32.4 to 32.8 per mille) and those in its offing or just to the east of it (<32 per mille).

The western end of any summer profile along this line, whether for 1913 or for 1915 (fig. 154), is interesting chiefly for its demonstration that off Massachusetts Bay water less saline than about 32.5 per mille occupies a cross section hardly less extensive than in May (fig. 126), though with the isohaline for that value pointing to some tendency for the fresher water to expand, seaward, over the salter. A relationship of this same sort also appears, as might be expected, on other profiles running out normal to the coast line, at several locations between Cape Ann and the Bay of Fundy, for the summers of 1912 and 1913 (Bigelow, 1914, figs. 30 to 32, and Bigelow, 1915, figs. 49 to 51).

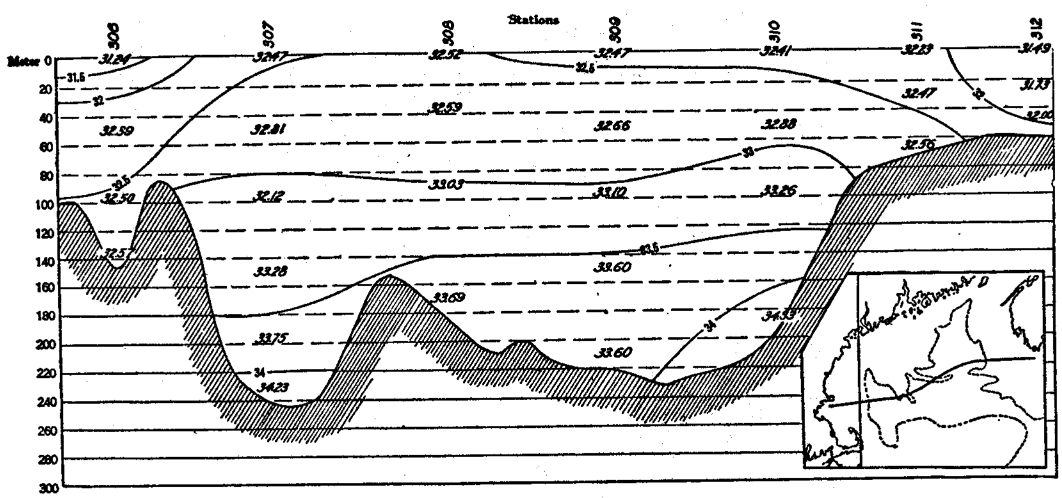

FIG. 154.—Salinity profile running eastward across the gulf from the mouth of Massachusetts Bay (station 10306) to the offing of Cape Sable (station 10312), August 31 to September 2, 1915

The summer profiles also supplement the charts for the 100-meter level in making clear the isolation of the sink off Gloucester (typical of all such sinks) by its barrier rim, resulting in the vertical homogeneity of salinity below the level of the latter, with a considerably lower value at the bottom of the sink than at an equal depth in the basin outside, which is characteristic of this situation.

The summer state of the water in the bowl inside Stellwagen Bank and in the deep channels that give entrance to it on the north and south is developed by profiles crossing the mouth of Massachusetts Bay for August 31, 1912 (Bigelow, 1914, fig. 33), July 19, 1916 (fig. 155), and August 22, 1922 (fig. 140). In the summers of 1916 and 1922 the saline bottom water (>32 per mille) of this bowl was continuous with the still higher salinities of the basin of the gulf outside via the floor of the channel next Cape Ann, but was entirely cut off to the southward by Stellwagen Bank. Consequently, any bottom drift that may have been taking place into the bay at the time, or shortly previous, must have followed the northern route.

In 1922, also, the upper 50 meters was least saline in the northern side of the bay, as might be expected if the general anticlockwise eddy enters it. This is probably the usual state at the end of the summer, also, unless temporarily interrupted by the offshore winds, when temporary upwellings may be responsible for surface salinities higher in the northern side of the bay than in the southern side (so confusing the picture), as appears on the July profile for 1916 (fig. 155).

Our own cruises do not afford summer profiles for the Bay of Fundy; but Mavor (1923) gives several such for August, 1919, cross-cutting the bay at intervals, all of which show the upper strata of water on the whole salter in the southern (Nova Scotian) than in the northern (New Brunswick) side. This distribution, as Mavor has brought out, corresponds to a tendency for the outpouring discharge of fresh water from the St. John River to spread southwestward along New Brunswick, while

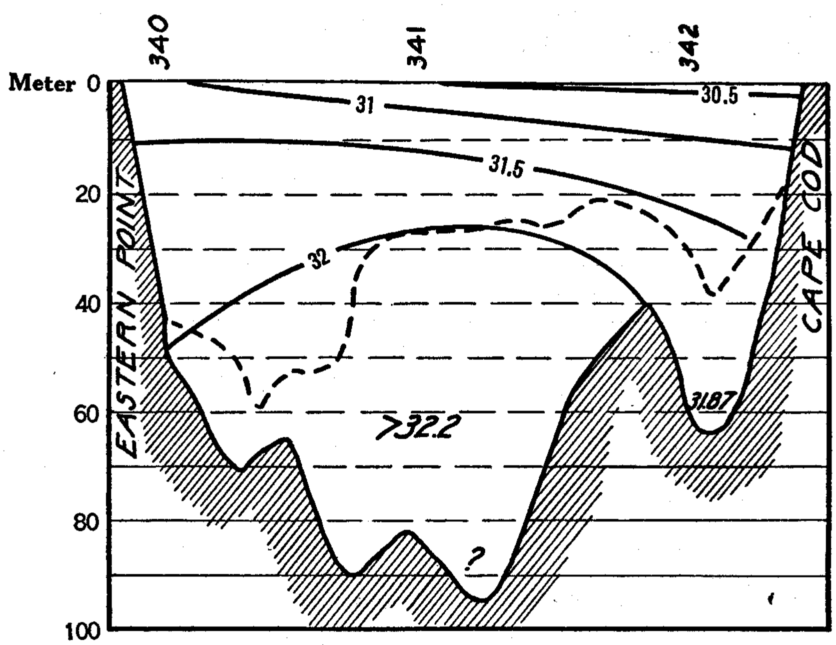

FIG. 155.—Salinity profile crossing Massachusetts Bay from the eastern point, Gloucester to Cape Cod, just inside Stellwagen Bank for, July 19, 1916. The broken curve gives the contour of the bank (stations 10340 to 10342)

the salter water (32 to 32.5 per mille) tends to bank up against Nova Scotia, giving a marked obliquity to the isohalines. In the bottom of the trough of the bay Mavor's profiles show the saltest and coldest water (33 to 33.1 per mille) as a longitudinal ridge, which he explains (Mavor, 1923, p. 364) as due to a rotation of the deeper water around this locality as a center. Concentration of the lowest salinities in the northern side also appears in the densities on profiles of the lower part of the bay for August, 1914 (Craigie, 1916a), proving this the usual summer state.

The characteristic contrast, below the surface, between the high salinity of the Atlantic basin and the much less saline water of the continental slope and shelf is brought out graphically for the summer months by the profiles (figs. 156 to 158) for 1914. Whether in July (figs. 156, 157) or in August (fig. 158), the successive isohalines show a sudden transition from the one to the other (most abrupt at this shoaler levels) and parallel to the edge of the continent. It is especially suggestive that while considerable overflows of water more saline than 33 per mille appear on the profiles in two regions—one from the Eastern Channel across Browns Bank, as just described (p. 788), and the other in the offing of Nantucket Shoals—neither profile (nor the chart for 200 meters, fig. 150) suggests any tendency for this most saline water to enter the Eastern Channel. On the contrary, the isohalines for the highest values at each level cross the latter, leaving the oceanic triangle occupied by the intermediate salinities of the slope water (33 to 35 per mille).

As to the date when bottom water of high salinity may be expected to drift in over the edge of the continent toward Nantucket Shoals, I can only point out that in 1913 water of 33 to 33.5 per mille and upwards in salinity was encountered at 40 meters over the outer edge of that sector of the shelf as early as July 10 (stations 10060 to 10062). In 1914 water of this high salinity had encroached on the southwestern part of Georges Bank by July 19 and had reached the 40-meter contour off Nantucket Shoals some time prior to the last week in August (fig. 145); but in 1916, a backward year (p. 772), the bottom water over this part of the shelf was only 32.5 to 33 per mille on July 19 to 25 (stations 10354 to 10355, fig. 159)—i. e., about 1 per mille less saline than at about the same season of 1913 or of 1914, corresponding almost exactly to the readings obtained there in May, 1920.

Water more saline than 35 per mille may be expected to wash the slope at the 100-meter level right across the mouth of the gulf at some time during the summer, and perhaps continuously throughout the summer during some years, for the Canadian Fisheries Expedition had 35.35 per mille at 100 meters on the slope of the La Have Bank in July, 1915 (Bjerkan, 1919; *Acadia* station 41), where the 100-meter salinity on July 28, 1914, was only 34.16 per mille (station 10233; both readings taken over the 450-meter contour line).

Only on one occasion have our lines reached water of full oceanic salinity (36 per mille)—namely, abreast the western end of Georges Bank on July 21, 1914 (p. 780, figs. 145 and 156). Failure to find water as saline as this at our outermost stations anywhere else between the offings of Chesapeake Bay and Cape Sable on any other cruise, or off Nova Scotia, suggests that this pure "Gulf Stream water" may be expected to approach the edge of the continent more closely thereabouts, as it moves northward in summer, than either to the west or to the east.

We have yet to learn whether oceanic water approaches so close to the edge of the continent every summer as it did in 1914. In 1913 and 1916 (the one an early and the other a late season in the sea) it certainly did not do so until well into the summer, if at all. We may assume, therefore, that the situation pictured on the July profile for 1914 (fig. 156) is most likely to be reproduced in August, taking one summer with another.

Although this highly saline water probably approaches within a few miles of the 200-meter contour at about this longitude (68° to 70°) by the end of every August, it has never been found actually encroaching on the continental shelf abreast of the Gulf of Maine or anywhere else along the North American littoral north of Chesapeake Bay at any season. Bjerkan's (1919) record of 35.9 per mille at 50 meters at the *Acadia* station 44 miles off La Have Bank on July 22, 1915, combines with our own data for 1914 (fig. 145) to show the isohalines for 35.5 and 36 per mille departing farther and farther from the continental edge, passing eastward from Georges Bank, and so leaving a less saline wedge (34.5 to 35.5 per mille) some 60 miles wide off the mouth of the Eastern Channel. This fact is worth emphasis as one of the numerous bits of evidence that the indraft that takes place into the eastern side of the gulf, via this channel, is constantly of the so-called "slope" origin

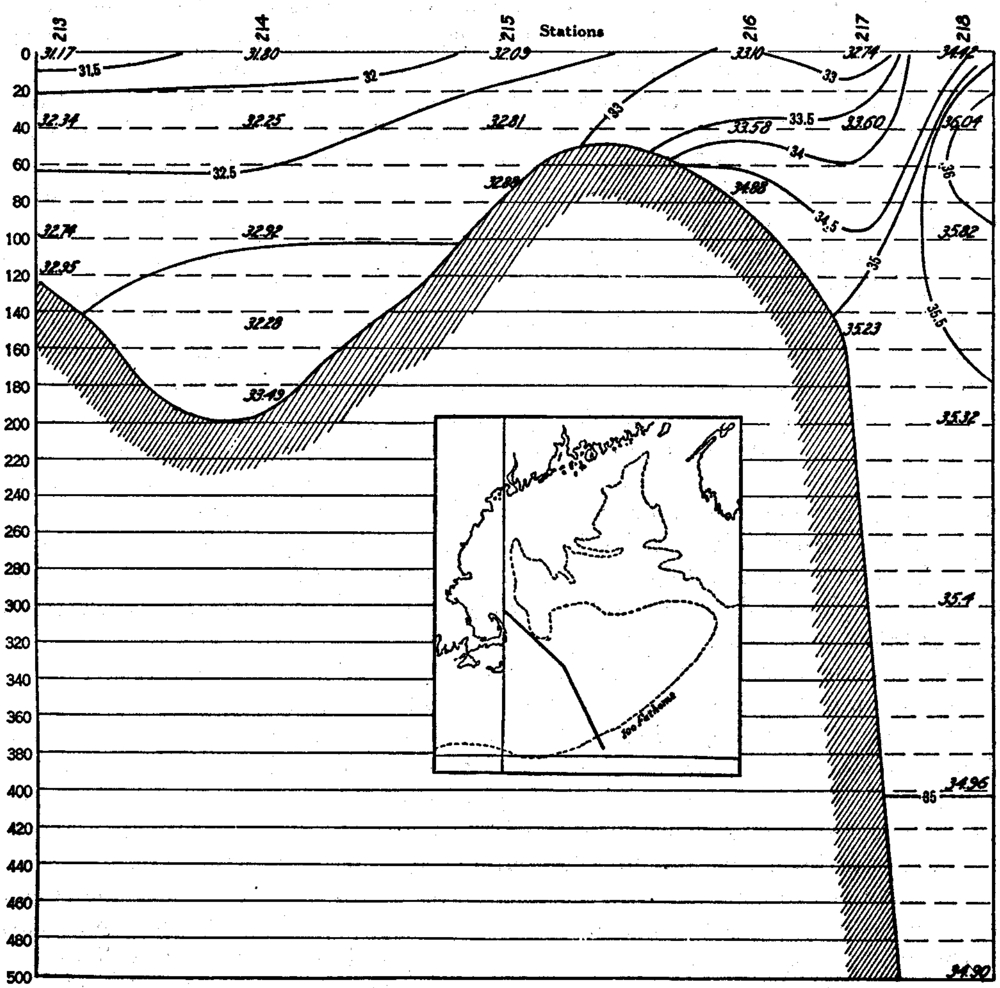

FIG. 156.—Salinity profil (running from a station (10213) off northern Cape Cod, southward across the western end of Georges Bank (stations 10215 and 10217), to the continental slope (station 10218), July 19 to 21, 1914

(p. 842), thus accounting for the rarity of tropical planktonic animals and plants within the gulf (Bigelow, 1925).

When the transition in salinity is as abrupt along the edge of Georges Bank as it was in July, 1914 (fig. 156), to speak of a salinity "wall" is excusable exaggeration. At such times the following waters may be named, successively, along any profile crossing Georges Bank from north to south:

First, in the basin to the north of the bank is the Gulf of Maine complex, ranging in salinity hereabouts from about 32 per mille at the surface to about 33.5 per mille at a depth of 200 meters and close to 34 per mille in the still deeper trough of the basin. The northern part of the bank is washed by the typical "banks" water, with a mean salinity of 32.5 to 33 per mille, which in the shoaler parts is kept nearly

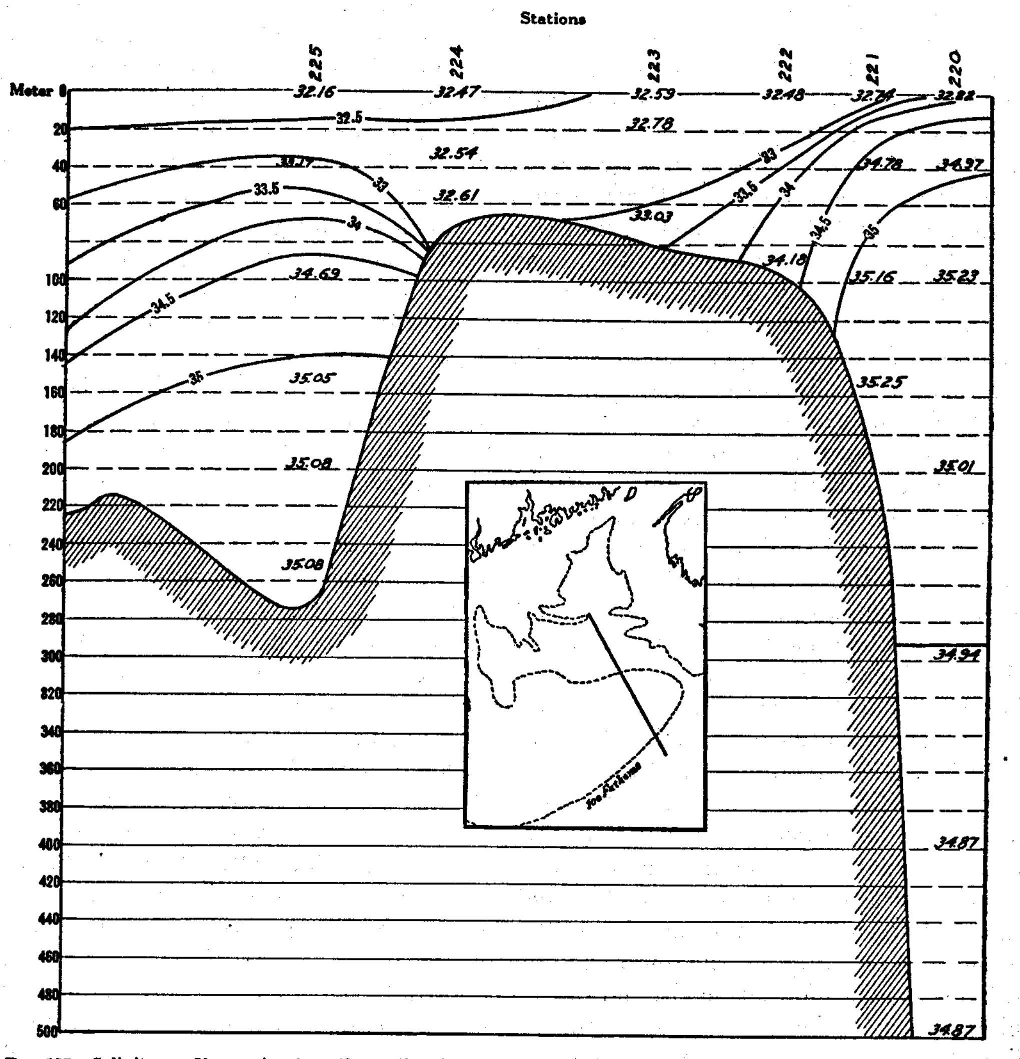

FIG. 157.—Salinity profile running from the southeastern part of the gulf (station 10225), southward across the eastern end of Georges Bank (stations 10221 to 10224) to the continental slope (station 10220), July, 1914

uniform, vertically, by tidal stirring. Over the seaward slope the zone of transition to the much more saline water is condensed into so narrow a zone that the successive isohalines become nearly perpendicular on the distorted scale adopted for the profiles, their precise degree of obliquity depending, of course, on the proximity of the oceanic water to the south. Finally, at the offshore end true oceanic or

"Gulf Stream" water more saline than 36 per mille will be met if the profile runs out far enough.

Farther east (fig. 157) a rather different picture results from the homogeneous state of the water maintained on the bank by active tidal stirring, as described above (p. 770); but the contrast between the comparatively low salinity there and the much higher values on the continental slope to the south, on the one hand, as well as in the basin of the gulf to the north, on the other (34 per mille), affords a graphic illustration of the extent to which the contour of the bottom controls the relationship of water masses that differ in salinity because of different origins. Note also the abrupt transition from the thick layer of 35 per mille water in the bottom of the basin to the very much lower salinity (about 32.2 per mille) at the surface on this profile, reflecting the considerable difference in density that exists in summer between the slope water and the surface stratum beneath which this intrudes.

All three summer profiles of the continental shelf for 1914 (figs. 156, 157, and 158) show extremely uniform salinities of 35.2 to 35.4 per mille bathing the bottom at about 100 to 200 meters depth all along the slope abreast the gulf; and as the Canadian Fisheries Expedition also had 35.4 per mille at 200 meters just outside the continental edge in the offing of Shelburne, Nova Scotia, on July 22, 1916 (Bjerkan, 1919; *Acadia* station 41), this may be taken as normal for the summer.

In February and March, the reader will recall, only the western sector of this zone was as salt as this; in July, 1916, the values were slightly below 35 per mille (fig. 159)—differences that apparently reflect the normal seasonal succession in the inshore and offshore movements of oceanic water. On this assumption the maximum salinity of the eastern sector of the warm zone for the year is not far from 35.5 per mille, and the minimum certainly is as low as 34.5 to 34.7 per mille.

At depths greater than 400 meters the bottom water on this sector of the continental slope is always close to 34.9 to 35 per mille in salinity, perhaps never varying more than 0.2 per mille from this mean value at any time of year.

Lower salinities off Marthas Vineyard in July, 1916 (fig. 159), than in August, 1914 (fig. 158), no doubt reflect the normal seasonal succession in this part of the sea, suggesting that values less than 32 per mille will seldom be recorded on this line after July, and that water more saline than 33 per mille may be expected to move inshore over the bottom during that month and August (p. 793). The fact that the water over the median sector of the shelf was nearly homogeneous in salinity, surface to bottom, at that time (fig. 158), contrasting with pronounced stratification closer into the land, on the one hand, and farther out at sea, on the other, is unmistakable evidence of active circulation. The abrupt transition from low salinities to high ones over the edge of the continent, made evident on the profile by the isohalines for 34, 34.5, and 35 per mille, also marks this as the zone of contact between two distinct masses of water at the time (p. 795). The rather unusual vertical distribution of salinity about one-third the way out from the land where the mid stratum was less saline than either the surface above it or the bottom, has been commented on (p. 779).

These two profiles (figs. 158 and 159) are also of interest from a more general viewpoint as illustrations of the general increase in salinity from the land seaward, which is characteristic of the whole continental shelf between Cape Cod and Chesapeake Bay.

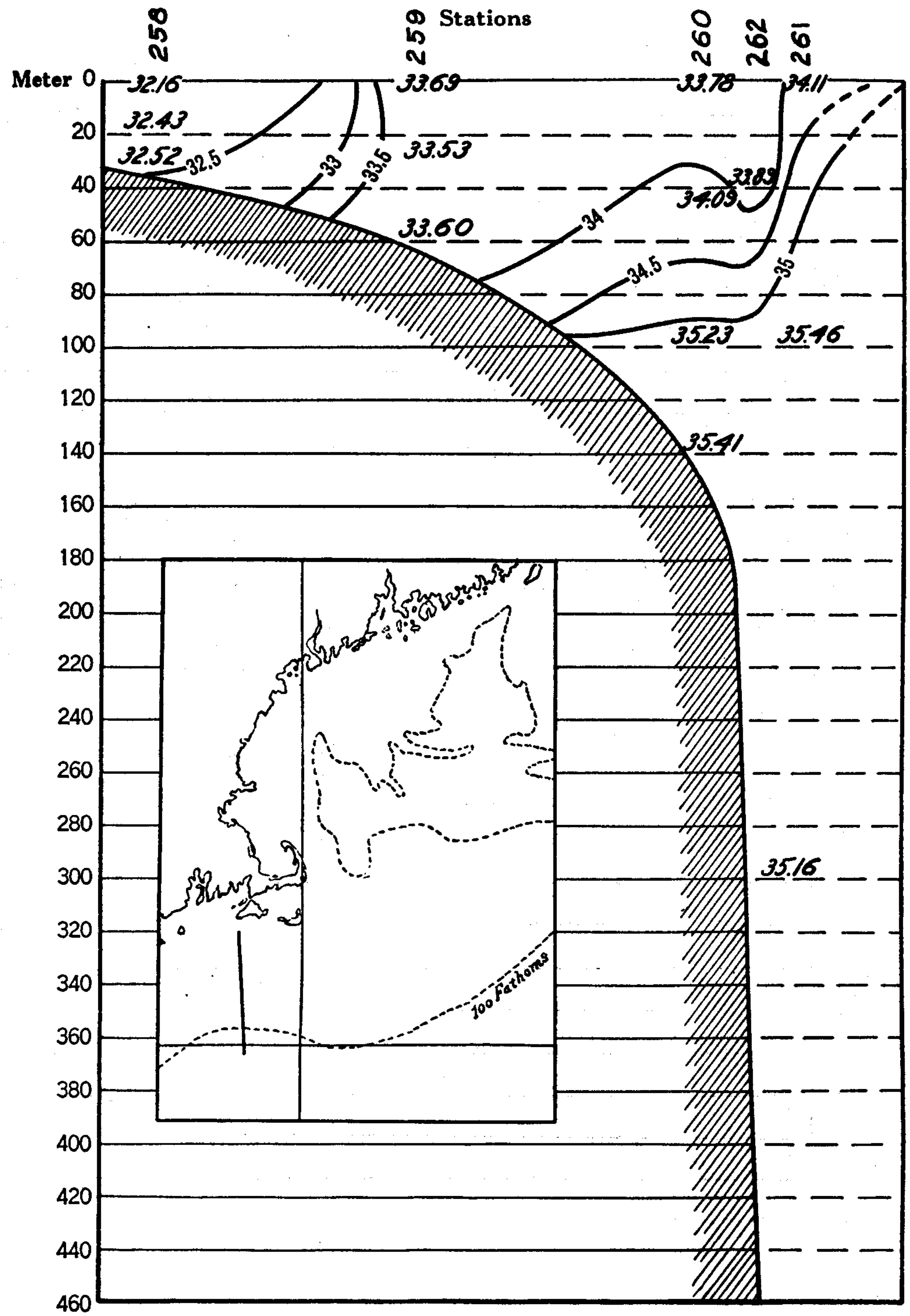

FIG. 158.—Salinity profile running southward from the offing of Marthas Vineyard (station 10258) to the continental slope (station 10261) for August 25 and 26, 1914

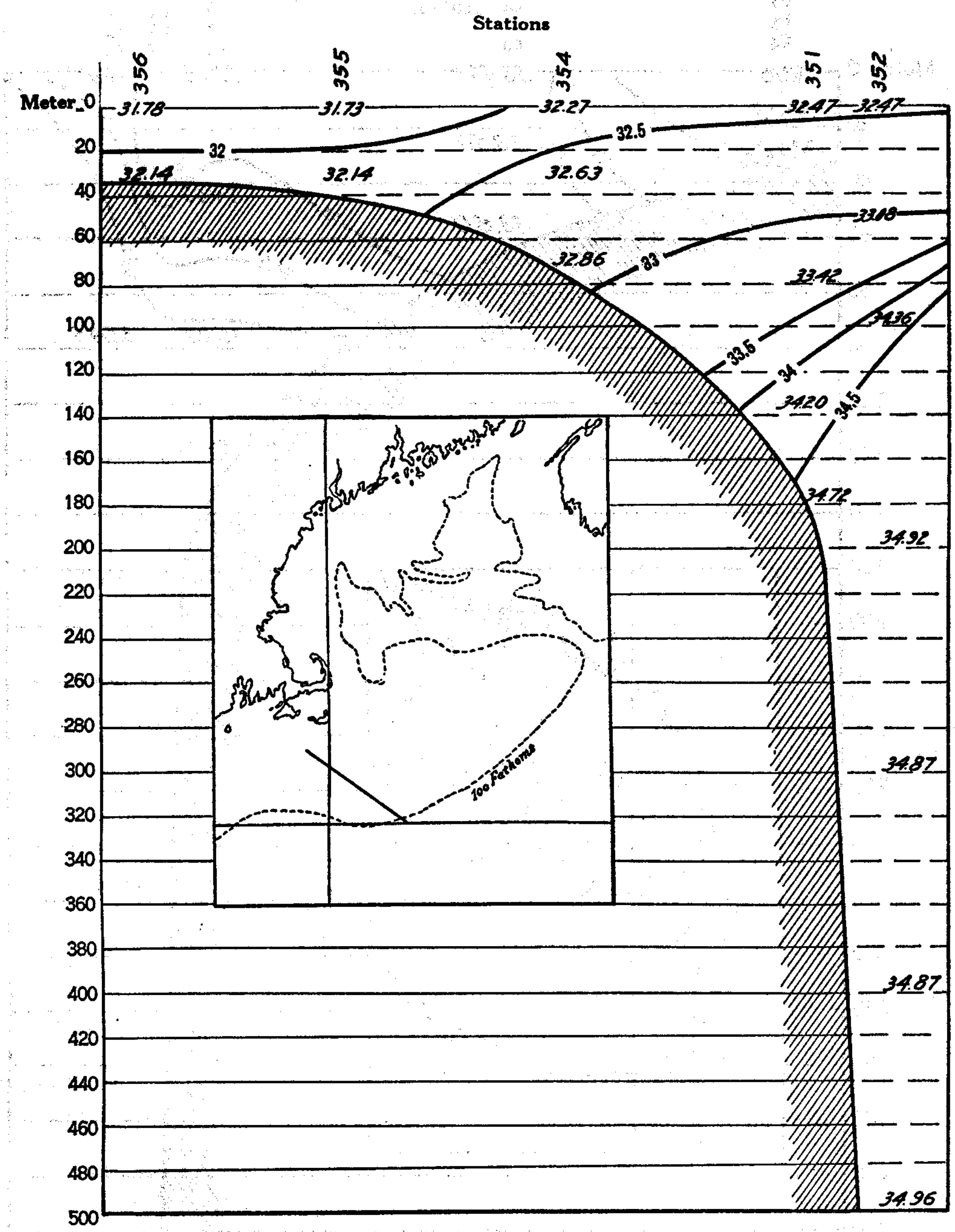

FIG. 159.—Salinity profile running southeasterly from the offing of Marthas Vineyard (station 10356) to the continental slope (station 10352) for July 24 to 26, 1916

SALINITY IN AUTUMN AND EARLY WINTER

Observations taken through September and October of 1915, in early November of 1916, and at the end of that month in 1912 afford a general picture of the salinity of the northern and western parts of the gulf at that season. Vachon (1918) and Mavor (1923) also give autumnal data for 1916, 1917, and 1919 for various localities in the Bay of Fundy region.

In 1915 pairs of successive stations were occupied at intervals, expressly to show the seasonal changes, if any; and when the salinities for these are plotted an increase of 0.6 to 1.1 per mille is shown at the surface all along the coastwise belt east of Cape Elizabeth from July and August to October—an increase of about 0.5 to 0.9 per mille at the 50 to 60 meter level. At the same time, however, the vertical range of

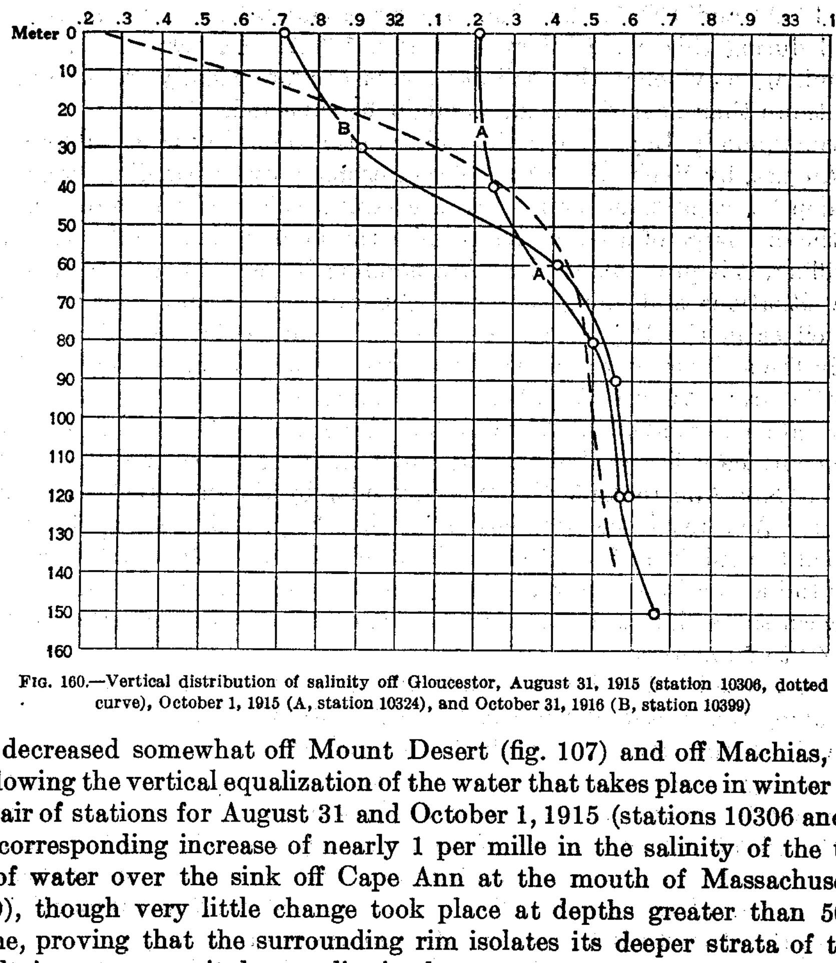

FIG. 160.—Vertical distribution of salinity off Gloucester, August 31, 1915 (station 10306, dotted curve), October 1, 1915 (A, station 10324), and October 31, 1916 (B, station 10399)

salinity decreased somewhat off Mount Desert (fig. 107) and off Machias, a change foreshadowing the vertical equalization of the water that takes place in winter (p. 801).

A pair of stations for August 31 and October 1, 1915 (stations 10306 and 10324), show a corresponding increase of nearly 1 per mille in the salinity of the upper 40 meters of water over the sink off Cape Ann at the mouth of Massachusetts Bay (fig. 160), though very little change took place at depths greater than 50 meters meantime, proving that the surrounding rim isolates its deeper strata of this bowl effectively in autumn as it does earlier in the season.

The superficial stratum off the mouth of Massachusetts Bay also seems to have experienced some increase of salinity during the early autumn of 1916, the surface value being about 0.5 per mille higher at the station in question (10399) on October

31 than at a locality a few miles to the south on August 29 (station 10398), with almost precisely the same values at depths greater than 50 meters as in August and October, 1915. Increasing salinity in the upper strata, contrasted with constancy in the deep water, is thus a regular accompaniment of advancing autumn in this locality.

Tidal currents being comparatively weak here, autumnal salting at the mouth of Massachusetts Bay reflects some widespread change of the same sort, not simply vertical mixing *in situ*. The extent to which the inner waters of the bay share in this alteration during the early autumn is therefore interesting. Unfortunately, this can not be stated, for want of data at successive dates throughout any given season; but the fact that the surface of the northern side of the bay had virtually the same salinity on October 26 and 27, 1915 (stations 10338 and 10339), as a month earlier (stations 10320 and 10321), but had become about 0.5 per mille more saline near Cape Cod during this same interval (station 10322, 31.4 per mille; station 10337, 31.9 per mille), is evidence that salinity increases more rapidly at the mouth of the bay in autumn than near the head, as might be expected.

Passamaquoddy Bay, across the gulf, is also somewhat more saline in October than in August, by Vachon's (1918) observations, notwithstanding irregularities in the mid depths, caused, no doubt, by the strong tides. As Passamaquoddy Bay receives the discharge of a large river, while the land drainage into Massachusetts Bay is trifling, it is probable that a corresponding increase in salinity takes place in estuarine situations and along the shore generally all around the coast line of the gulf as well as in the Bay of Fundy, where Mavor (1923) records a considerable increase in the salinity of the upper 80 meters of water between Grand Manan and Nova Scotia[4] from August 25, 1916, to November 6.

Such data as are available for October make it likely that this general salting brings the surface salinity above 32 per mille all along the coastal belt to the north and east of Cape Ann (outside the outer islands) by the first week of the month in most years. As a result the area less saline than 32 per mille which skirts the whole coast line of the gulf from Cape Cod to the Bay of Fundy in July and August (p. 769), contracts to include Massachusetts Bay alone by mid autumn. A similar relationship between the salinities of late summer and of mid autumn prevails down to a depth of 40 to 50 meters.

Some increase in the salinity of the upper stratum of water was naturally to be expected along this sector of the coast line in autumn as the effects of the vernal discharges from the rivers are gradually dissipated. If this process of mixture is accompanied by an active indraft of highly saline water into the bottom of the gulf the increase will involve the whole column right down to the deepest stratum of the basin; otherwise the intermingling of comparatively low salinities from above with higher salinities from below must result in lowering the salinity of the deeper strata while raising that of the shoaler. The vertical distribution of salinity is therefore an index to the strength of the bottom drift in autumn.

Unfortunately, no deep stations were occupied during the autumn of 1915; but on November 1, 1916, observations taken in the basin off Cape Ann (station 10401) yielded decidedly lower salinities in the deepest stratum than we have ever found

[4] *Prince* station 3 (Mavor, 1923, p. 374)